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“Effect of renewable energy- generation technologies on electricity prices”

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ABSTRACT

The integration of renewable-generation technologies in the energy mix is crucial for the achievement of the goals settled regarding technological development, environmental sustainability, energy dependence and security of supply.

Favourable regulatory frameworks have been established in Spain during the last decades with the aim of encouraging the investment in renewable technologies. But, and moreover, further benefits are said to be achieved with high penetration rates of renewables into the electric markets. There is evidence supporting the fact that electricity prices are cheapened because of the participation of renewable generation plants in the Day-ahead Market of electricity.

Thus, the aim of this thesis has been devoted to study the implications renewable generation has on the prices of electricity and their respective impact on its sustainability. Simulations of the auction process carried out at the 2017 Daily Market of electricity were performed for two different scenarios regarding the energy mix: one such as that of 2017 and other identical to this, but with no renewable generation.

The results obtained confirmed the fact that renewables undersell electricity prices. For year 2017, the presence of renewable generation units in the Day-ahead Market of electricity cheapened final electricity prices by 7,5%. This is due to the fact that renewable generation units sell their energy at quasi-zero prices, as a result of their low opportunity costs compared with fuel-based generation technologies. However, the savings generated by this cheapening of prices could not cover all the regulated costs associated to the specific remuneration provided to renewable technologies. Still, it must not be forgotten that year 2017 in Spain was extraordinarily bad regarding renewable generation, due to the poor production of hydraulic power stations, resulting from the severe droughts that took place during that year.

These results were compared with those published by *APPA*, an association of firms operating in the renewables sector, and several conclusions were drawn. The results of the simulations performed in this thesis under Simple Bidding conditions converged almost totally with those published in the report (97% similarity in prices and 100% in savings). Therefore, it was concluded that there was enough evidence to believe the figures published by *APPA*, regarding the prices cheapening and savings generated by renewables, might have been computed under Simple Bidding conditions. These figures sized the prices reduction in the Day-ahead Market at 16,4% while the actual computed cheapening under Complex Conditions was of 12,1%.

As additional implementations, it would be interesting to extend the study period to the last ten years, so that trends regarding the cheapening of electricity prices due to renewables integration can be drafted and analysed. This way, further implications of renewables integration on the system's costs and prospects could be outlined.

Keywords: Bids, Electricity Markets, Matching, Simulation, Prices, Bids, Auction, Savings, Cheapening

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1. INTRODUCTION

1.1. Motivations and context

Renewable energy-generation technologies provided 46,3% of the installed power capacity in Spain at 2017 and provided a share of 33,7% of the overall electricity generation in this country. The positive effects of the integration of this kind of technologies is widely known: socio-economic and environmental benefits arise as a result of their development and use. To absorb these positive externalities, the installation of these kind of generation technologies has begun to be encouraged from the UE to its Member States during the last decades, with Spain among them. Moreover, several goals regarding renewables generation coverage ratios and installed power capacity shares have been settled through European directives and guidelines, for the 2020, 2030 and 2050 horizons. Programmes and regimes have been created with the aim of assessing this integration both nationally and internationally.

More concretely, the Spanish Government finally established in 1997 the so-called *Special Regime*, that settled the regulatory and economic framework under which “special” generation units were given incentives to generate electricity and install new plants. Throughout the last years, this regime has been under constant evolution until 2013, when it was finally suppressed. Instead, a specific remuneration system for co-generation, renewables and waste-based generation technologies was used. Thus, these generation units were remunerated through two different channels: the revenue associated to the price matched at electricity markets in the bid-auctioning process and an additional specific remuneration, which varied with different factors associated to the plant’s characteristics and operational parameters. However, almost no subsidies are currently devoted to renewable-generation plants, as a result of the progressive constraining of the remunerative regime, achieved through regulatory updates. The new installed renewable-power capacity is now adjudicated through an auction system.

However, criticism regarding renewables integration in Spain has emerged as a consequence of the uncertainty surrounding it; symmetrically similar to that of any new-born technology in views of revolutionizing its sector. Thus, some of the negative aspects associated to their integration are usually brought out when discussing about renewables mid-term horizon: their effect over the tariff deficit, the limitation of the resource disposal to climate conditions, the curtailment of the incentives for enhancing conventional generation technologies, etc.

Therefore, this thesis aims to deeply study one of the most used arguments against this criticism: the cheapening effect renewables have on electricity prices. The hesitations concerning the sustainability of its integration in the electric sector will be studied from an economic point of view. Therefore, conclusions regarding the implications renewables have over the Daily Market operation, the main responsible of electricity prices settlement, are to be drawn at the end of this paperwork.

1.2. Goals and scope

This document aims to reach relevant conclusions regarding the effect of renewables integration on electricity prices by means of simulating two different scenarios: one energy mix such as the 2017 Spanish one and another identical to this, but with no renewable generation. This way, by means of performing a comparative analysis between these two scenarios, the different prices settled at the electricity markets of both cases can be easily contrasted, so that the effect renewable generation has on it can be isolated and analysed.

Then, a deep understanding of the functioning of the Spanish Daily Market of electricity and the variability of its output associated to renewable generation is meant to be acquired. Also, conclusions regarding the data model fitting and solidness will be drawn after performing a comparative analysis of results with those published in the 2017 *APPA* report [1]. This report is yearly published by *APPA*, an association of companies related to the renewable energy sector. In this document, a macroeconomic analysis regarding renewable technologies is performed to study the impact of their integration. Thus, current information about the overall status of the renewables sector is provided in the document.

In addition to this, the implications of this price variability will be used to study the savings generated by renewables (if any), so that prospects regarding renewables economical self-sustainability can be reached.

1.3. Thesis structuring and procedure

To accomplish the above-mentioned goals, it is essential to properly step-up the procedures to be executed in the overall analysis, together with carrying out an efficient articulation of the tasks to be performed.

Thus, the thesis will be structured in four different phases, as stated below:

1. Documentation: Information regarding the Spanish electricity sector and markets will be retrieved with the aim of building a theoretical background standing for their operation and status at 2017. This step turns vital as a deep understanding of the mentioned fields is mandatorily required for the optimal execution of the following.
2. Data model execution: The necessary input data needed to perform the mentioned simulation of scenarios will be collected for its later processing. Through *Matlab*-based software tools, a prototype simulating the matching process of the Spanish Daily Market of electricity will be implemented. To do so; different scripts, functions and algorithms will be programmed. This is, undoubtedly, the key step of the overall process. Thus, all the programming skills of the developer must be put in practice to properly debug the matching process of electricity prices taking place hourly in the Daily Market, so that a solid data model can be implemented. Once this is achieved, the simulations of the different scenarios will be carried out so that their outcomes can be properly stored for further study. The analysis of these results will draw the final conclusions of the thesis.
3. Comparative analysis: The results obtained from the simulations performed will be compared with those published by 2017 *APPA* report so that conclusions regarding the reliability and solidness of the data model implemented can be reached.

4. Conclusions: Considering all the elements that have shaped both the data model and the analysis performed, conclusions converging with the previously stated thesis' goals and objectives will be drawn.

1.4. Available means and software-based tools employed

Only *Matlab*-based software tools will be employed for the simulations of the Daily Market operation for the different scenarios to be implemented. The reasons behind the choice of this software tool are its simplicity and cleanliness, together with the availability of an online user-support tool [2], hosted by *Matlab*. At its website, *Matlab* users can find useful documentation detailing and clarifying the operation of the different implementable commands, data types, structures and functions. This way, new users with limited experience in programming software (such as the author) can deeply understand most of the features of the tool, enabling them to properly implement functional pieces of code for the tasks required.

Other software tools such as *Microsoft Excel's Visual Basic* have been initially discarded due to its not-so-good user interface and solidness, besides the considerably smaller online-available collections of documentation regarding its operation, compared with *Matlab's*.

Regarding the data collections to be used, only information of public access found at *ESIOS* and *OMIE's* websites is used and processed in this thesis.

2. STATE-OF-ART OF RENEWABLE ENERGIES IN SPAIN

2.1. Energy mix in Spain in 2017

Data collections from *Red Eléctrica de España (REE)* towards Spanish energy sector [3] states that the installed power capacity in the Spanish energy mix shrank for the second consecutive year, by 0,5% with respect 2016. Much of this had to do with the definitive closure of the *Santa Maria de Garoña* nuclear power plant, sized at 455 MW of production. Thus, at this point, 104,122 MW constituted the whole installed capacity of the Spanish energy-generation mix in 2017, with a 46,3% of its share corresponding to renewable-generation units.

By means of an efficient use of this capacity, Spain and Portugal managed to supply 96,4% of the overall energy demanded in their territory, with the remaining 3.6% being covered by energy imports coming from neighbouring countries. However, in 2017, Spanish energy imports grew at lower rates than the exports (7,6% against 12,2%, with respect 2016); setting, for the second year in a row, a net importer balance regarding energy trading. Therefore, since most part of its demand is covered with domestic production, the peninsular territory could be said to be self-sustainable from a technical point of view. However, this has another reading: 66,3% of the overall electricity generated in Spain in 2017 came from non-renewable energy technologies using coal and natural gas as main fuels, of which 73,3% need to be imported [4].

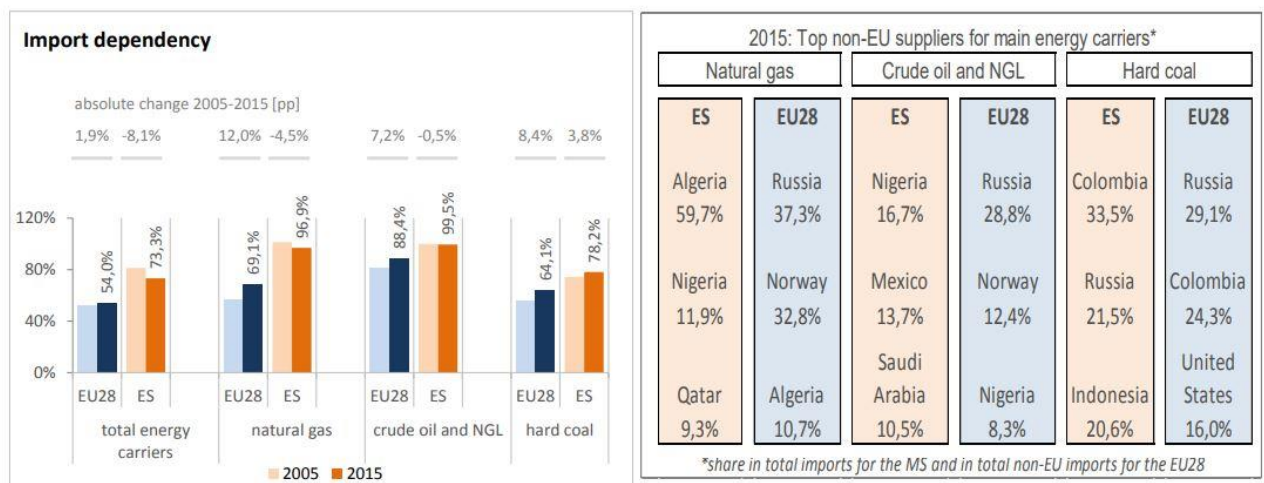


Figure 1: Graphical representation of Spanish import dependency by kind of fuels. SOURCE: EU Commission [5].

Therefore, as seen in *Figure 1*, among all EU Member States, Spain stands out with one of the most severe energy dependencies (about twenty points over the European average). This fact turns even more critical when attending to natural gas and oil, which reached in 2015 almost absolute maximums (96,6% and 99,5%, respectively) in the degree of external dependence. This makes the country extremely sensitive and vulnerable to the fossil fuels' prices fluctuation, as shall be seen later in the report.

Hence, renewables integration arises as one of the implementable potential solutions to mitigate this dependence. The main renewable-generation technologies do not use any fuel other than natural resources such as wind, sun or water flow. Other renewable technologies, such as biomass, do use fuels. However, these are made out organic matter, usually coming from urban, farming and sewage sludge residues so that there is no need to massively import them, as they aim to be produced domestically.

2.2. Main renewable technologies

As stated above, 66,3% of the electricity generated in Spain came from non-renewable generation technologies. Thus, the remaining 33,7% corresponded to renewables production. However, it must be noted that during 2017 renewable generation share fell by 16,3%, with respect the previous year [3]. This falling was mainly due to the extraordinary lack of hydroelectric generation, resulting from the severe droughts that struck the country during this year, which also fell by 49.1%. These falling placed the 2017 renewable generation on its lowest production output since 2009 [6]. Consequently, both combined-cycle and coal-fired power generation outputs grew, contributing to a 17,9% increment of the CO₂ emissions regarding 2016.

On the other hand, installed renewable power capacity growth rates remained essentially frozen, following the trend of the years subsequent to 2013. *Figure 2* shows the evolution of these figures in the last years:

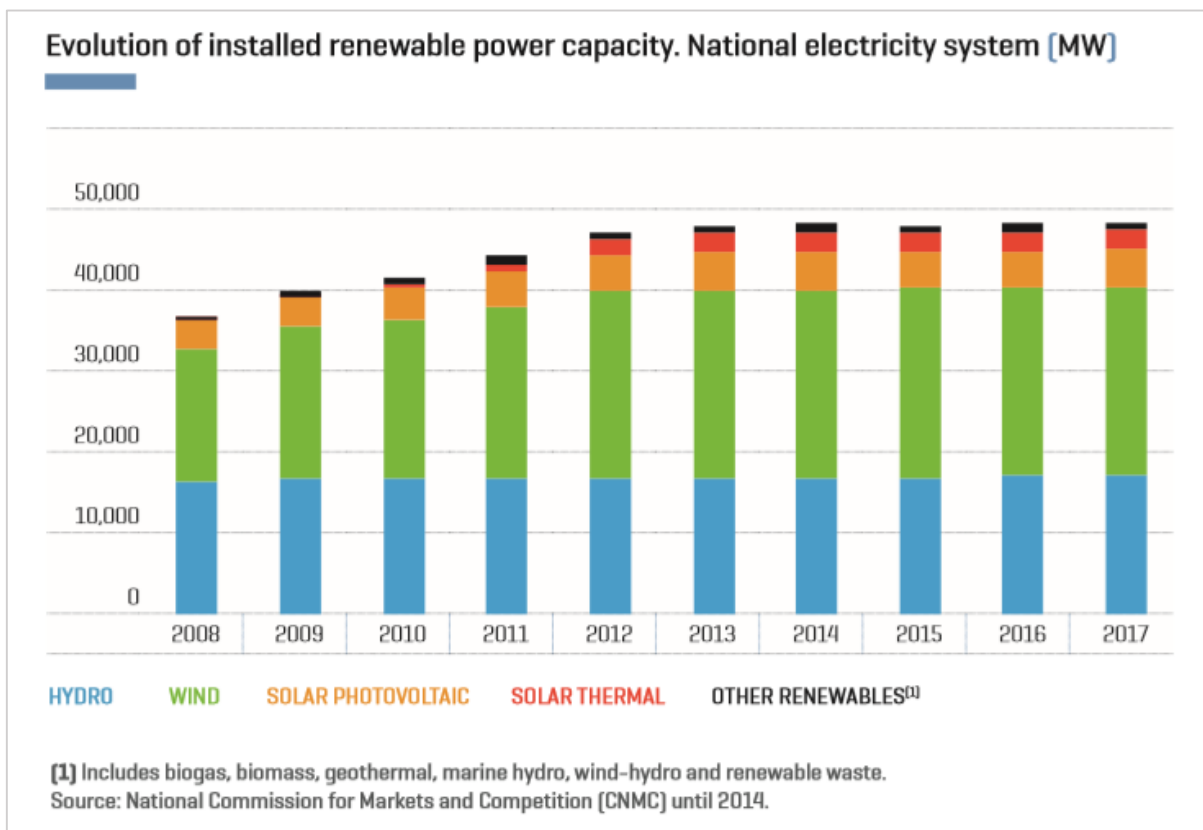


Figure 2: Evolution of the installed renewable power capacity in Spain throughout 2008-2017. SOURCE: REE [6].

Thus, wind energy is the most relevant renewable technology in the energy mix, followed by the hydraulic. In fact, wind energy stands out as the runner-up regarding the overall installed power capacity by technologies, behind only nuclear (*Figure 3*).

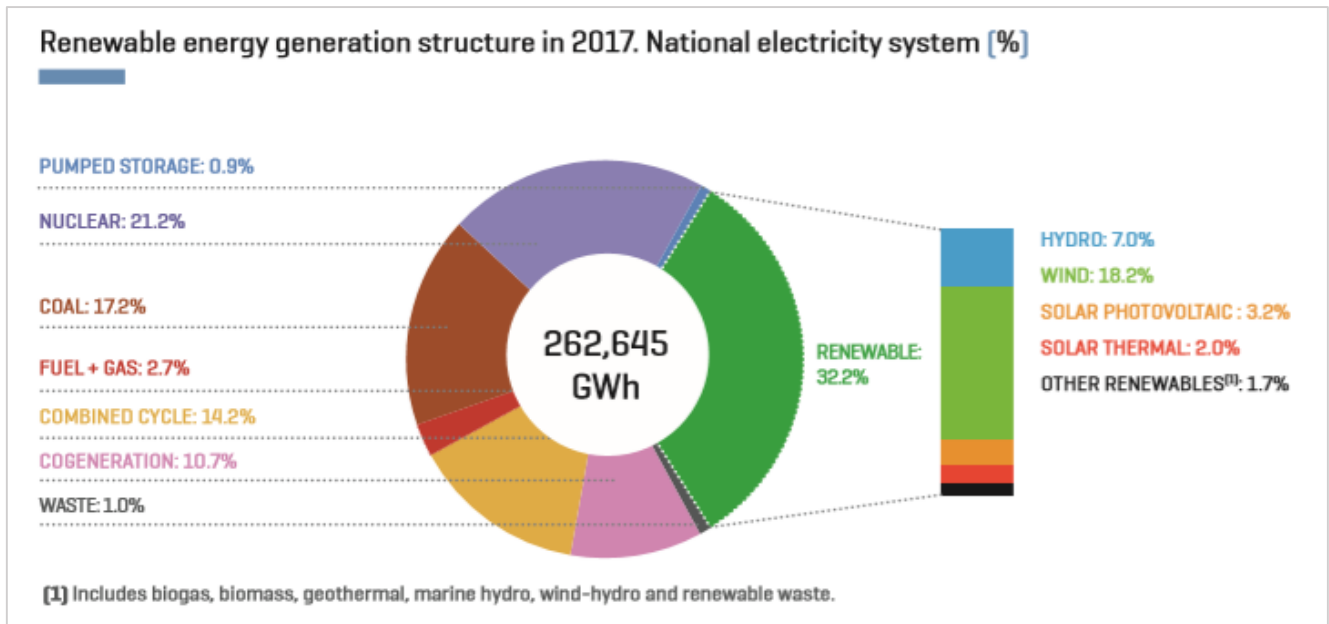


Figure 3: Installed renewable power capacity by technologies in Spain during year 2017. SOURCE: REE [6].

This is due to the fact that wind energy is, probably, the renewable technology with the smallest rates of dependence on meteorological conditions. Wind energy assures a better resource disposal than the hydro power, which is the second leading renewable technology in terms of installed power capacity. Hydraulic energy, as seen in the 2017 reports of *REE*, halved its generation output when unfavourable climate conditions arose. On the contrary extraordinary meteorological conditions causing weak winds are not usually sustained over time, unlike droughts. Moreover, wind energy ensures way more potential generation hours than solar energy, for example, which is only able to generate electricity during sun hours. Also, technological development has managed to reduce the uncertainty surrounding new-born wind power projects. The elaboration process regarding the preliminary wind atlas and wind-resource studies has been noticeably optimized and enhanced [7].

Thus, the aggregated effect of all these facts has given incentives to increase the spending in wind energy throughout the last years, driving this generation-units to reach the second position in the ranking in installed power capacity by technology in 2008.

2.3. Spanish regulatory framework

The regulatory framework under which renewables have constrained its operation and integration has been in constant evolution since the 1980s. The implementation of these enhancements has been driven by the pretension of mitigating Spanish energy dependency.

However, the first relevant change introduced in the regulatory framework regarding renewables dates from 1997. The *Law 54/1997* dated 27th November, regarding the Electric Sector established the so-called *Special Regime*. Renewables, co-generation and residual-based generation technologies would operate within the constraints of this regime [8].

Associated to the growing general interest in this kind of technologies, the *Royal Decree-Law 841/2002* settled the incentives to their participation in electric markets, prior obligation to inform about their generation forecasts and, by means of obliging retailers to acquire the produced energy, establishing annual premiums to the renewable sector [9].

These premiums were said to be the main responsible for the severe increment of Spanish tariff deficit throughout the years in which the financial crisis, initiated in 2008, stroked the country. Thus, the *Royal Decree-Law 9/2013*, dated 13th July, was published with the aim of establishing urgent measures to ensure the financial sustainability of Spanish electrical system [10]. New remunerative regimes were settled for all generation technologies so that, the *Special Regime* established in *Law 54/1997* was finally suppressed. This new-born remunerative regime was later updated in subsequent pieces of regulation. Thus, *Law 54/1997* was finally repelled by the subsequent *Law 24/2013*, dated 26th December, regarding the Electric Sector

Thus, under the new economical regime of the Electric Sector, first declared in *Royal Decree-Law 9/2013* and updated in current years, generation plants are remunerated following the dual-term regime stated below. Thus, they are eligible to receive [11]:

1. One revenue associated to the sale of energy evaluated at the matched market price.
2. Another specific revenue associated to two different concepts:
 - a) Investment: additional remuneration per unit of installed power is given to those facilities which cannot pay-off their initial investment with the market revenue.
 - b) Operation: additional remuneration is given to all facilities which cannot pay-off their operational expenses with the market revenue. This amount is sized at the difference between the mentioned costs and revenues.

However, the Government reserves the right to provide the renewables, residual and co-generation technologies extraordinary pieces of supplementary remuneration; as long as these satisfy the goals settled by the *EU* or either ensure costs and energy dependence reductions, regarding the overall energy mix.

Nevertheless, renewable-generation facilities can avail themselves to this regime, counting from the date of the expenditure of the installation authorisation, only during twenty years for wind technologies and up to thirty for *PV* plants. Thus, expiration dates for this specific remuneration to be perceived by renewables have been settled. This fact drives renewable generators to be obliged to seek and explore new methods aiming to optimize their operation, in order to make it profitable in the long run. Renewable technologies need to evolve to ensure their profitably in the following years, once the public funds devoted to their activity are extinct.

Moreover, throughout the next years, new regulatory modifications such as that of *Royal Decree-Law 413/2014* updated the economic constraints of the additional operational remuneration to be perceived by these plants, so that they have been considerably limited. Moreover, investment incentives are now provided through auction systems in which generators willing to invest in renewables are awarded with a marginal subsidy. Thus, it can be said that public spending in renewables funding has fallen markedly since 2016, when the first auction for the adjudication of 700 MW of renewable power capacity for installation was held. The year after, the Spanish Government succeeded in the execution of several subsequent auctions. Thus, given the efficient economic performance achieved in these processes and the increasing demand of generators, further auctioning processes can be expected to take place in the following years. Moreover, in order to accomplish the goals settled by the *EU* in the 2030 horizon, the estimated need of renewable power capacity to be installed yet is sized at 22.000 MW [11].

Therefore, as seen above, their operation in the Daily Market and the effect of their integration in the energy mix on electricity prices need to be deeply studied. Thus, the price matched at the Daily Market of electricity is the key factor to understand their profitability in the medium term. Also, by means of studying this parameter, some of the most important socio-economic benefits associated to their integration can be analysed; as initially aimed in the goals declaration of this thesis.

2.4. Costs of the Electrical System

As in any cost-benefit analysis, the economic sustainability of renewables is intimately related to the costs of the system. Year 2013 constituted a perfect example of this: the costs associated to the premiums remunerated to the *Special Regime* were said to be the main causes of the tariff deficit growth, so that urgent regulatory measures were taken to mitigate the worsening of the situation, compromising renewables survival in the medium term.

The evolution of this tariff deficit during the years previous to the regulatory change can be seen in *Figure 4*.

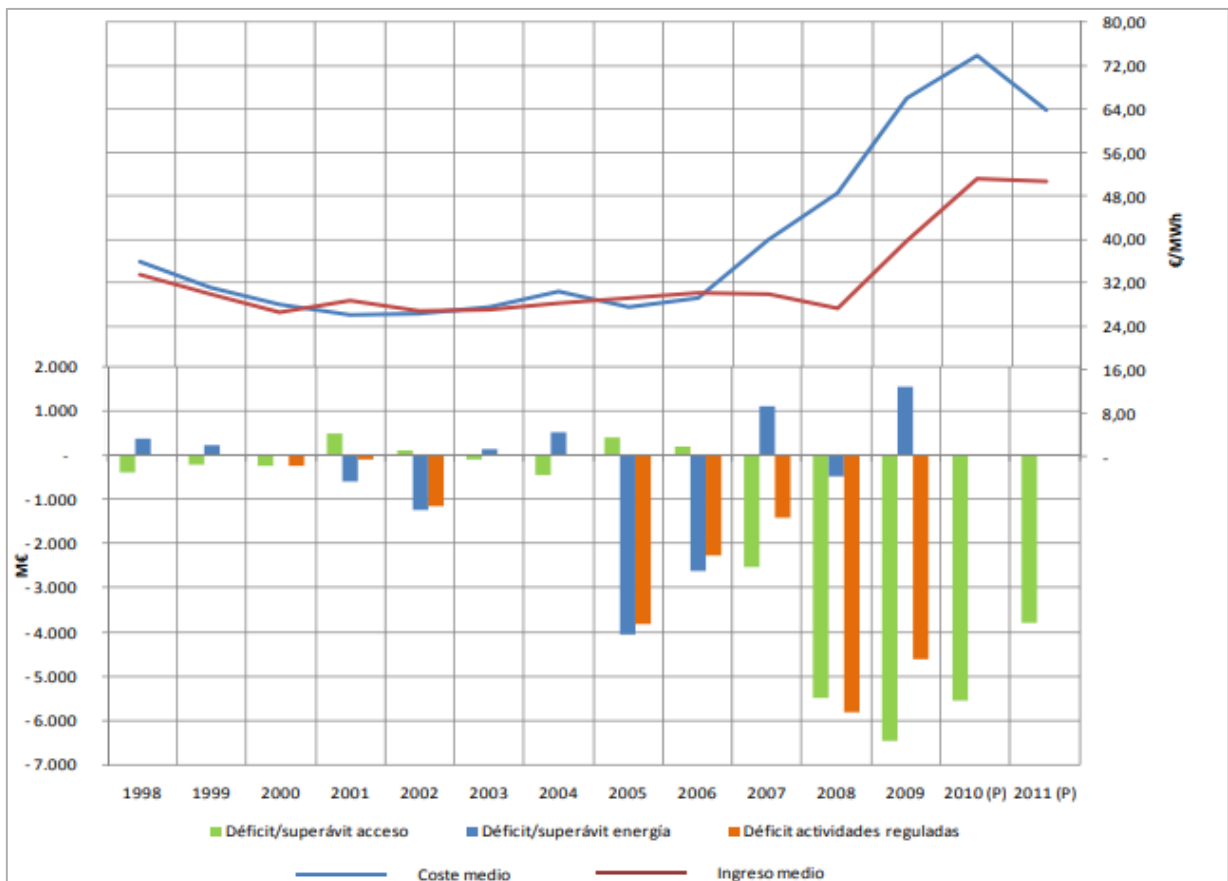


Figure 4: Evolution of the average costs and revenues and its associated deficit during 1998-2011. (P) prevision. SOURCE: CNE [12].

Thus, as stated by the CNE (currently integrated in the CNMC) [12], before *Royal Decree-Law 9/2013* the costs of the regulated activities were noticeably larger than the revenue coming from the payment of the regulated term of electricity prices by consumers. Moreover, the growing tendency of the tariff deficit seems to firstly take-off in 2002, right after the *Royal Decree-Law 841/2002* establishing the first premiums to the *Special Regime*.

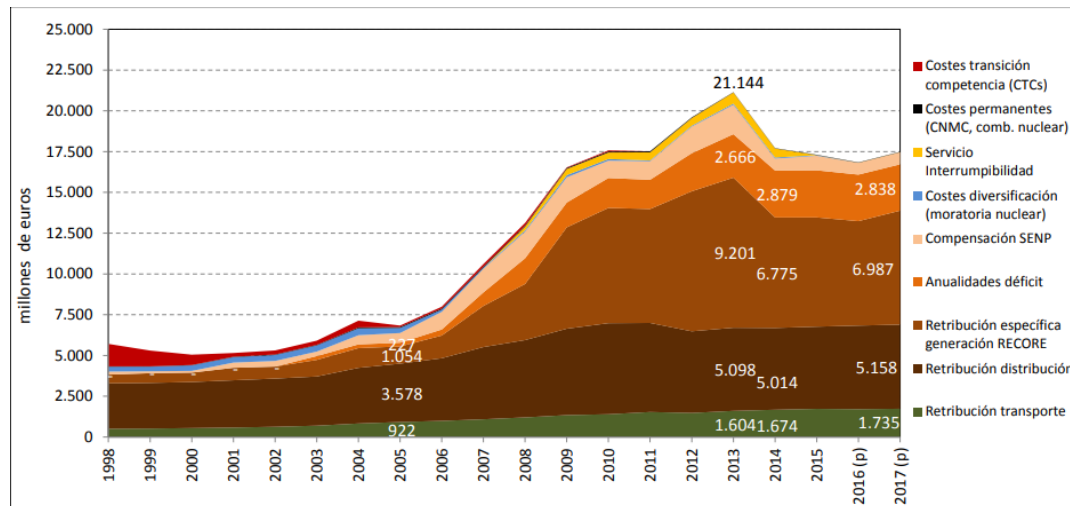


Figure 5: Electric System's cost evolution during 1998-2017. (P) prevision. SOURCE: CNMC [13].

Figure 5 shows the weight of the premiums to the *Special Regime* regarding the total regulated costs of the system. It can be seen how these began to grow also in 2002, from which it can be deduced that they were indeed the main responsible of the growth of the tariff deficit. However, after 2013, it can be seen how these began to moderate, having the consequent positive impact over tariff deficit (Figure 6). Yet, it is still necessary to face shares standing for annuity payments to this tariff deficit in the regulated price of electricity.

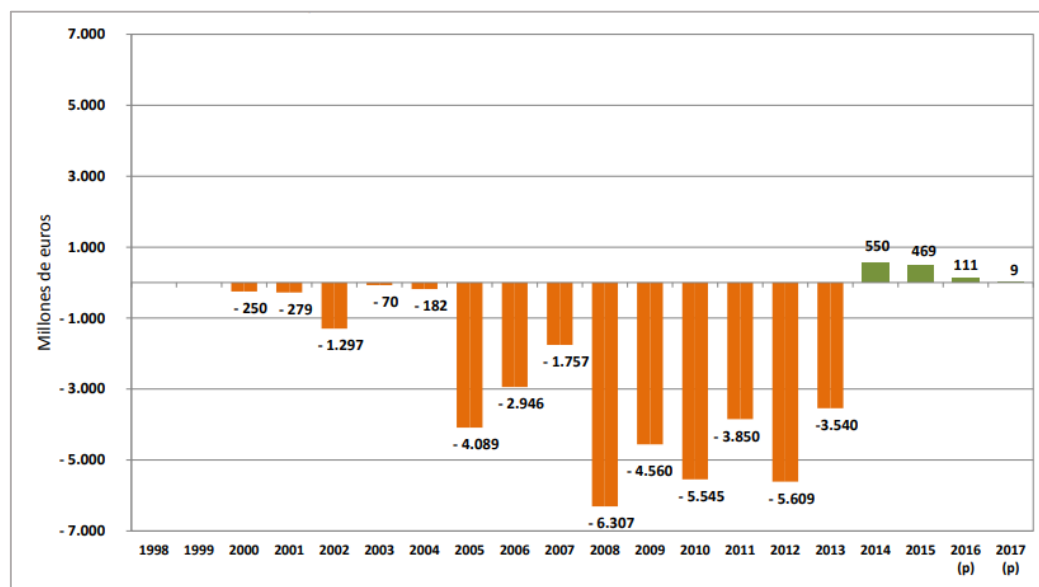


Figure 6: Electric System's tariff deficit evolution during 1998-2017. (P) prevision. SOURCE: CNMC [13].

2.4.1. Costs face-off: Regulated term in the electric bill

Thus, the Electric Sector splits its total costs in two: the regulated and the production costs; which are paid-off through two different terms in the final price of electricity.

The regulated costs of the system are divided into:

- Access costs: including payments to the transmission and distribution grids networking the peninsular territory and its commercial management,

complementary payments to the generators operating in non-mainland territory, payments to the old *Special Regime*, payments associated to the additional remuneration to be perceived by generators stated in *Royal Decree-Law 413/2014*, shares to Market and System Operators (*OMIE*, *REE*) and regulator (*CNMC*), annuity payments to the tariff deficit, compensations to nuclear generators for the nuclear moratorium, costs associated to the disposal of nuclear residues and the strategic stock of nuclear fuel, etc.

- Capacity payments: including those incentives willing to promote the building of new power plants (auctions) and those devoted book power availability of technologies to be used in peak demand periods (interruptibility). These bookings can be only executed in a one-year horizon.

Thus, access costs are remunerated through the payment of a regulated term in the final price of electricity, through the so-called access tolls; which are composed of:

- One constant term (€/kW) for contracted power, in order to guarantee anytime the supply of the contracted power.
- Another variable term (€/kWh) for energy, which directly depends on the consumed energy.

Access tolls are annually settled by the *MINCOTUR*, who reserves the right to review them when extraordinary conditions arise, on a quarterly basis maximum. Thus, the aim of this tolls is to completely pay-off the costs. These are settled one-year-ahead on the basis estimation of the regulated costs for the following year. Thus, if predictions mismatch the real costs, these cannot be fully covered. Hence, the difference between total revenue generated by this access tolls and the regulated costs of the system is the tariff deficit. *Figure 7* graphically shows the yearly tariff deficit generated as the result of the mentioned fact. However, it can be also noticed how these began to fall after 2013, with *Royal Decree-Law 9/2013* and its subsequent regulatory updates.

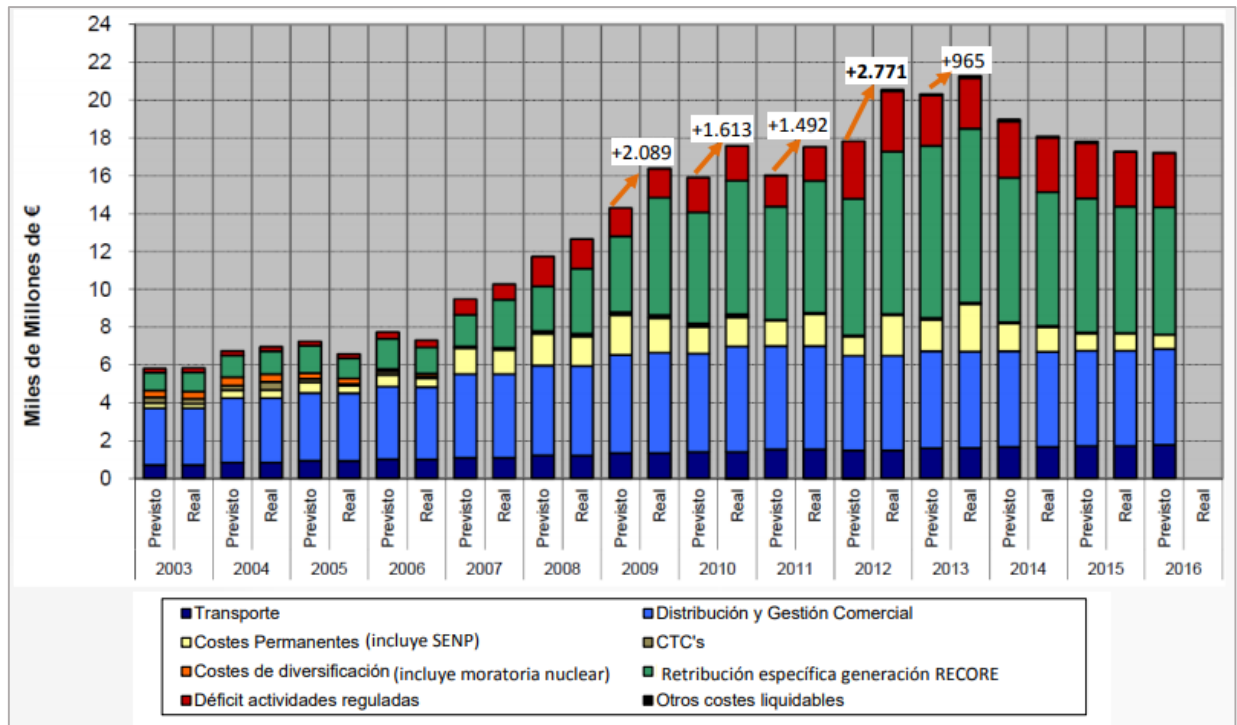


Figure 7: Electric System's evolution of predicted vs. real regulated costs during 1998-2017. (P) prevision. SOURCE: CNMC [14].

On the other hand, production costs are constituted by the amount to be paid to generators for the total of energy fed to the network. This energy is evaluated at the prices matched at both forward and spot markets, as it will be explained in the following chapter.

3. IBERIAN ELECTRICITY MARKET (MIBEL)

As the main goal of this thesis is to study the effect of renewables on the price of energy matched on the Daily Market, prior to this analysis, some introductory paragraphs need to be devoted to explain the functioning of the electric markets in Spain.

The first detail to point out is that the Electric Sector in Spain has not always worked the way today does. Before 1997, it was structured as a regulated system in which prices settled by the Government paid-off all the incurred costs. These payments; mostly devoted to cover the operation costs of generation, transport and distribution of energy; were made to the few private companies operating in the sector. Thus, with the drastic regulatory implications of *Law 54/1997*, Spanish Electrical System was liberalized with the aim of increasing companies' competitiveness and system's overall efficiency. Thus, as introduced in the previous point, the activities of the sector were differentiated into two kinds: regulated (transport and distribution) and partially-liberalized (production and commercialization). Therefore, there are two key actors responsible for the operation and competitiveness of the sector: System Operator and Market Operator.

3.1. Operators and markets

Red Eléctrica de España (REE) is the System Operator in Spain. Its main functions are to ensure the correct operation of the system and guarantee, at any time, the continuity and safety of the supply negotiated in the wholesale markets. To do so, some of the markets devoted to satisfy this technical conditions of the system (matching between demand and supply at any time) are also operated by them.

However, the Market Operator is in charge of supervising the matching process between the sale and purchase bids periodically auctioned to the market. Thus, it is responsible of satisfying, in the most efficient way for the end-users' purse, the scheduled demand of energy with the most convenient sale bids, in views of maximizing social welfare. Thus, we can distinguish two different kinds of markets: spot and derivatives.

In spot markets, commodities such as electricity are traded for immediate delivery. Hence, the main spot markets in the peninsular territory are then operated by the *Operador del Mercado Ibérico - Polo Español (OMIE)*: the wholesale Daily Market and the Intraday Market. These two markets trade electricity to be finally delivered few hours after their adjudication.

Future or derivative markets, on the contrary, perform electricity trades in which the delivery date is settled in a way longer horizon (counting from several days after the adjudication to years). These markets, in peninsular territory, are operated by *Operador del Mercado Ibérico-Polo Portugués (OMIP)*. However, bilateral contracts are also carried out at *OTC* markets [11].

Thus, all these markets are jointly operated by Spain and Portugal through their integration into the *Mercado Ibérico de la Electricidad (MIBEL)*. *Figure 8* shows their timely sequence and schedule.

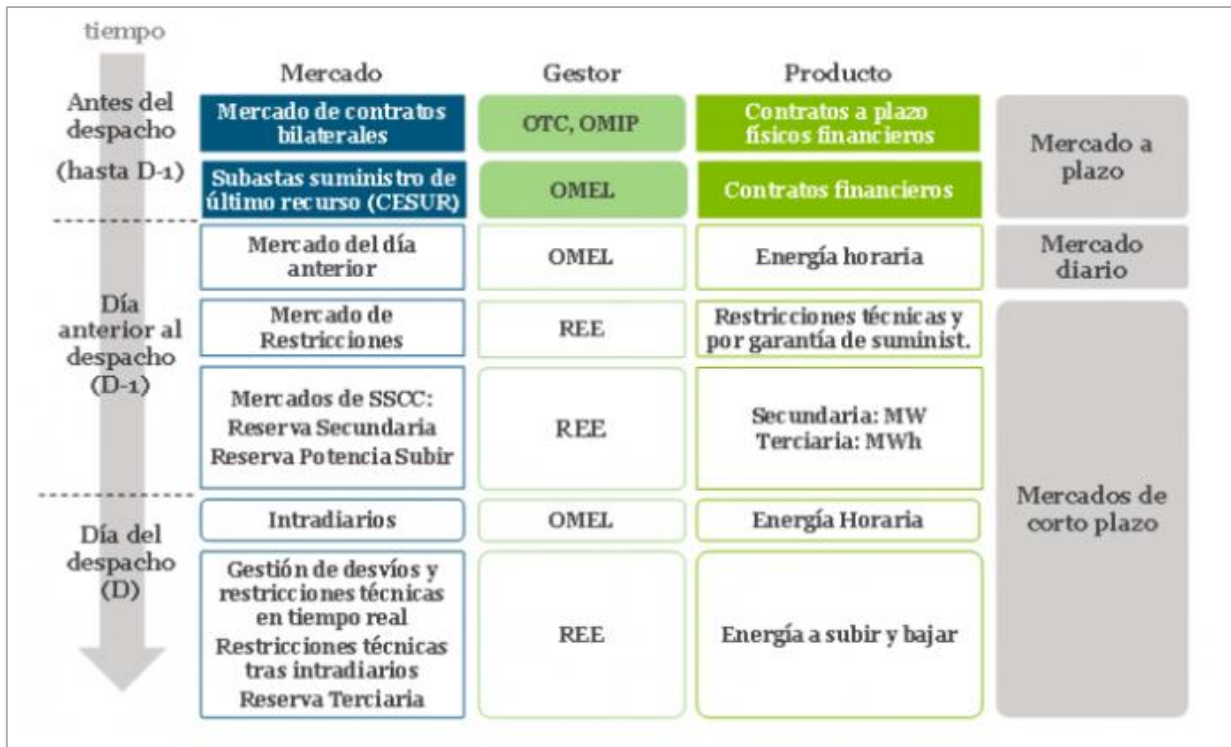


Figure 8.: Timely sequence of all MIBEL markets. SOURCE: *Energía y Sociedad* [11].

3.2. Agents

Thus, different natural and legal persons have the capacity to take part in the trading process performed in these markets by means of auctioning sale or purchase bids, prior commitment to undertake the established requirements. Hence, different agents can operate in the above-mentioned markets [15]:

- Electricity generators: they are responsible for the electricity production, together with the setting-up, maintenance and operation of the plants needed to perform these task.
- Retailers: they re-sell the energy bought at the markets to end-users or other retailers. *Reference* retailers work constrained to the *PVPC* (*Precio Voluntario al Pequeño Consumidor*) regime, under which they are forced to sell electricity to end-users at a given price, settled by the Government.
- Consumers: they can buy the energy directly at the market by means of auctioning purchase bids or through retailers.
- Representatives: they are authorised by third parties to bid in their behalf.
- Load balancers: these are consumers enabled to re-sell electricity to services devoted to the charging of electric vehicles.

4. DAILY MARKET

From all the *MIBEL* markets, the Daily Market is, undoubtedly, the most relevant regarding electricity prices settling. In 2017, the matched price at the Daily Market (also called *pool*) weighted the 68,43% of the final price of electricity, after its negotiation in the subsequent markets. Moreover, the amount of energy traded in the *pool* constituted the 78% of the overall energy traded in all the remaining markets. The participation in the Daily Market is mandatory for all the units not subjected to bilateral contracts.

4.1. Bids submission

As stated in *Figure 8*, the Daily Market is held *D-1*, one day before the delivery of the purchased energy to the buyer. Thus, all agents taking place in the auctioning process must submit their purchase (retailers, representatives and consumers) or sale bids (generators, load balancers) to *OMIE* no later than 12:00 the day before the day of delivery. Thus, each agent is able to submit bids containing up to 25 blocks to the auction process, each for the hour of the following day (taken also into account the extra hour associated to the time change in summer).

This bids can be either simple or complex. By means of submitting simple bids, agents transfer the Market Operator an amount of energy and its corresponding price for each of the hourly blocks. However, in complex bids, agents determine additional conditions to be fulfilled in the matching process. Consequently, if these are not fulfilled, the matching process of the given unit is not accomplished. Otherwise, the fulfilment of these conditions and the effective matching of these units, usually, shifts the supply aggregated curve to the left, setting higher matched prices and smaller matched amounts of energy. However, this doesn't apply for early morning hours, in which complex bids may set even lower matched prices than simple ones, due to the moderated demand. Still, it can be said that complex conditions set important constraints to the matching process [16]. The above-mentioned conditions are those of indivisibility, load gradient, minimum income and scheduled stop.

These are stated by *OMIE* at its market activity rules, available at its website [17]:

“The indivisibility condition enables a minimum operating value to be fixed in the first block of each hour. This value may only be divided by applying distribution rules if the price is other than zero.

The load gradient enables the maximum difference between the energy in one hour and the energy in the following hour of the production unit to be established, limiting maximum matchable energy by matching the previous hour and the following hour, in order to avoid sudden changes in the production units that the latter are unable to follow from a technical standpoint.

The condition of minimum income enables bids to be submitted in all hours, provided that the production unit does not participate in the daily matching result if the total production obtained by it in the day does not exceed an income level above an established amount, expressed euros, plus a variable remuneration established in euros for every matched MWh.

The condition of scheduled stop enables production units that have been withdrawn from the matching process because they fail to comply the stipulated minimum income condition to carry out a scheduled stop for a maximum period of three hours, avoiding stoppages in their schedules from the final hour of the previous day to zero in the first hour of the following day by accepting the first slot of first three hours of their bids as

simple bids, the only condition being that energy offered in bids must drop in each hour.”
[17]

4.2. Matching

The matching is performed under a marginalist mechanism, implemented by *EUPHEMIA* algorithm [18]: sale and purchase bids are sorted by growing and decreasing prices, respectively. This way, the matched price is settled as that of the last accepted bids; or, in other words, when both the demand and supply aggregated curves intersect. Hence, all units are remunerated by their respective auctioned energy at this matched price.

This way, the maximization of social welfare is achieved. This welfare is said to be the sum of both buyers and producers' surplus. Thus, the buyers' surplus is the difference between the marginal price initially auctioned in the purchase bid and the final matched price for that hours. The same applies to producers but with sale bids.

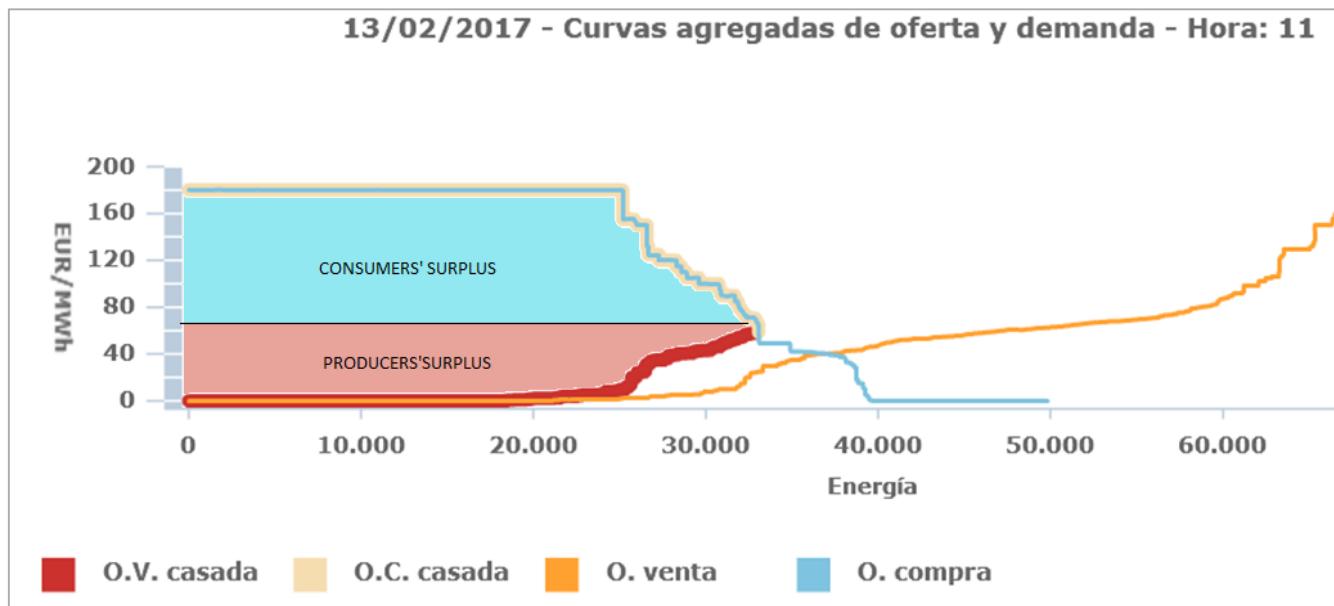


Figure 9: Example of the hourly matching performed at the Day-ahead Market. SOURCE: OMIE and own compilation.

Figure 9 represents graphically the achieved welfare with the marginalist mechanism characterizing the matching process, together with the shifting effect complex bids inclusion has on aggregated sale curves. As seen above, all the bids “entering” into the matching are those to the left of the accepted volume of energy.

Hence, from this it can be deduced that the Daily Market mechanisms drive agents participating on it to submit their bids at their marginal costs of production: the smaller the price at they bid, the bigger chance of entering into the matching and getting its corresponding piece of surplus. However, in order to achieve market efficiency, generators should not submit their bids at prices evaluated at their variable costs of production, but at their opportunity costs. These are defined as the costs the generator will avoid incurring in when choosing not to produce energy, in addition to the hypothetical revenue that is given up when taking this decision. For example, when a hydraulic power station decides to release its impounded reserves, the plant is giving up the possibility of releasing water at any other time with predictions of higher market prices. Also, the costs associated to, for example, the maintenance of the machinery regarding the water retrieval when that decision is taken, shall be taken into account as opportunity costs [11].

4.3. Merit-order effect of renewable generation

In order to understand the process through which renewables integration is said to undersell *pool* prices, some clarifications must be provided firstly.

Under the current regulatory framework, nuclear power plants submit their sale bids to the auction process at price zero: they are price takers. Due to their low stopping capability and the expensiveness and complexity of nuclear waste management, nuclear power plants present minimal opportunity costs. For them, it is much more expensive to give up producing rather than keeping on working [19].

Something similar happens with renewable generation units, which sell their generation at quasi-zero prices in the Day-ahead Market. This is due to the fact that no opportunity costs associated to fuel usage are incurred when deciding to keep on producing. Conventional generation units may consider to re-sell the fuel to be used in secondary markets, when prices of electricity are predicted to be lower than the revenue obtained through this process. Thus, most renewable technologies' opportunity costs will be mainly integrated by the costs incurred in when choosing to produce, such as maintenance costs. However, as these are moderated, they manage to auction bids at lower prices than conventional generation units.

Consequently, as sale bid curves are aggregated and sorted from least to greatest price, renewables (and nuclear) generators' bids are always included in the matching. Thus, the greater renewable generation, the greater demand coverage by this technology and the lesser remaining demand to be covered by more expensive ones. Therefore, conventional and expensive generation units are said to be "*price settlers*", regarding the electricity markets [20].

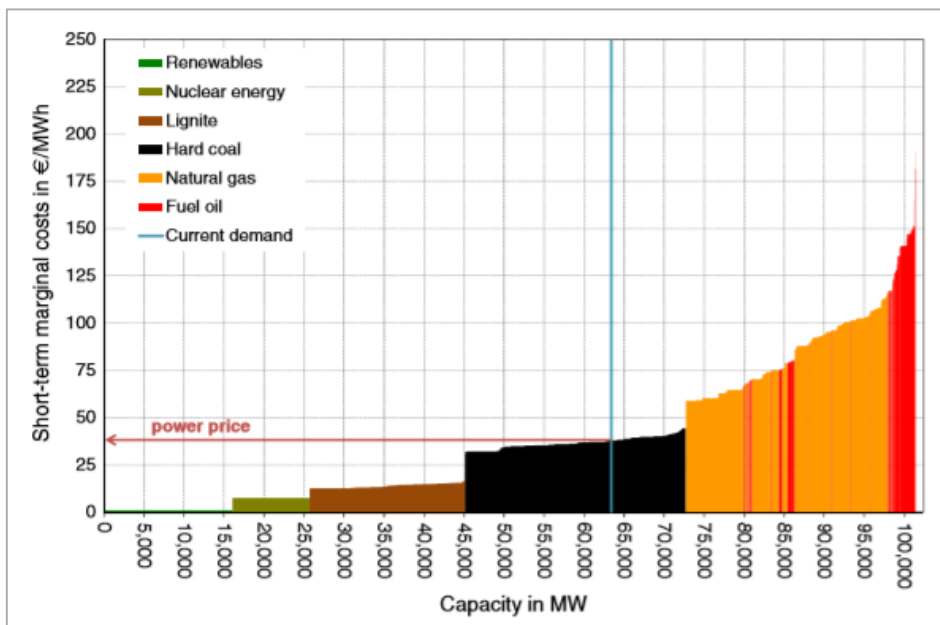


Figure 10: German merit order curve. SOURCE: Energy Economics [20].

Thus, there is evidence for stating that renewable energy integration is able to lower the prices matched at the Daily Market, as a result of the *merit-order effect*. Thus, the remaining pages of the thesis will be devoted to study its event. The goal will be to, first, confirm if renewables did undersell electricity prices in Spain during 2017 and, if so, compute to which extent and under which limitations this is true. To do so, the aggregated supply curves of bids auctioned to the Day-

ahead Market will be simulated, dismissing the bids coming from renewable generation plants, as stated in the introductory paragraphs. The goal will be to obtain a global picture similar to that of *Figure 11*.

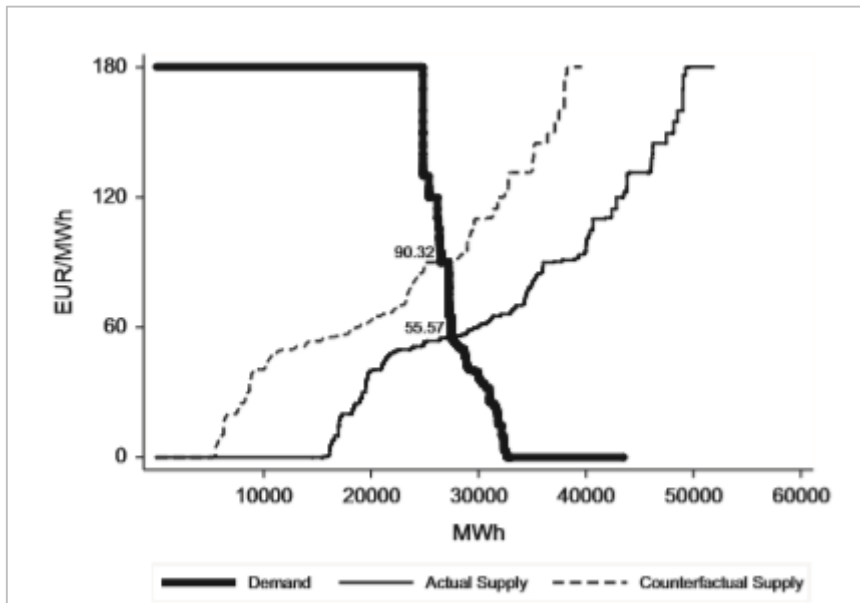


Figure 11: Hourly equilibrium between demand, supply and synthetic supply (excluding renewables) of electricity at the Day-ahead Market. SOURCE: Energy Policy [21].

5. MATCHING SIMULATION

5.1. Planning and execution

As previously explained in the introductory paragraphs, the main goal of this study is to reach conclusions regarding the effect of renewable energy-generation technologies on electricity prices. Thus, four different scenarios must be considered regarding the hourly matching process of 2017's Spanish Daily Market of electricity:

- a) Case 1: It considers the 2017 generation mix, including renewable generation, as the baseline scenario. The matching process at the Daily Market is simulated with simple bids files provided by *OMIE*.
- b) Case 2: It considers the real scenario of 2017's Spanish generation mix. The results of the Daily Market operation for this year were, obviously, computed under Complex Bidding conditions. Thus, these are the official matched prices and energies in 2017 provided by *OMIE*.
- c) Case 3: It considers a synthetic generation mix, such as that of 2017 but excluding renewable generation, as the baseline scenario. The matching process at the Daily Market is simulated with the same bids as those of *Case 1*, but dismissing sale bids auctioning renewable generation from the matching process.
- d) Case 4: It considers the same synthetic generation mix as that of *Case 3*. However, the results of the Daily Market operation for this year are not simulated, but computed out of the previous. Thus, this is the *goal* scenario. Its results will be later compared with those of *Case 2* so that conclusions can be drawn. Consequently, the matching results need to be inexorably computed assuming Complex Bidding conditions.

The matching process of *Spanish* electricity Daily Market for cases 1 and 3 is simulated, while *Case 2* is considered as the virgin scenario for the further calculations. *Case 4* is computed out of the results of the previous. In these different scenarios, the different bid units integrating each matching process will vary the hourly matched prices obtained. Once the simulations are performed, matching prices from cases 2 and 4 are analysed and compared in order to compute the savings in electricity prices associated to the integration of renewable-generation technologies in the energy mix, so that conclusions regarding the *merit-order effect* can be reached. *Figure 12* shows the flow-chart diagram of the main steps integrating the whole process.

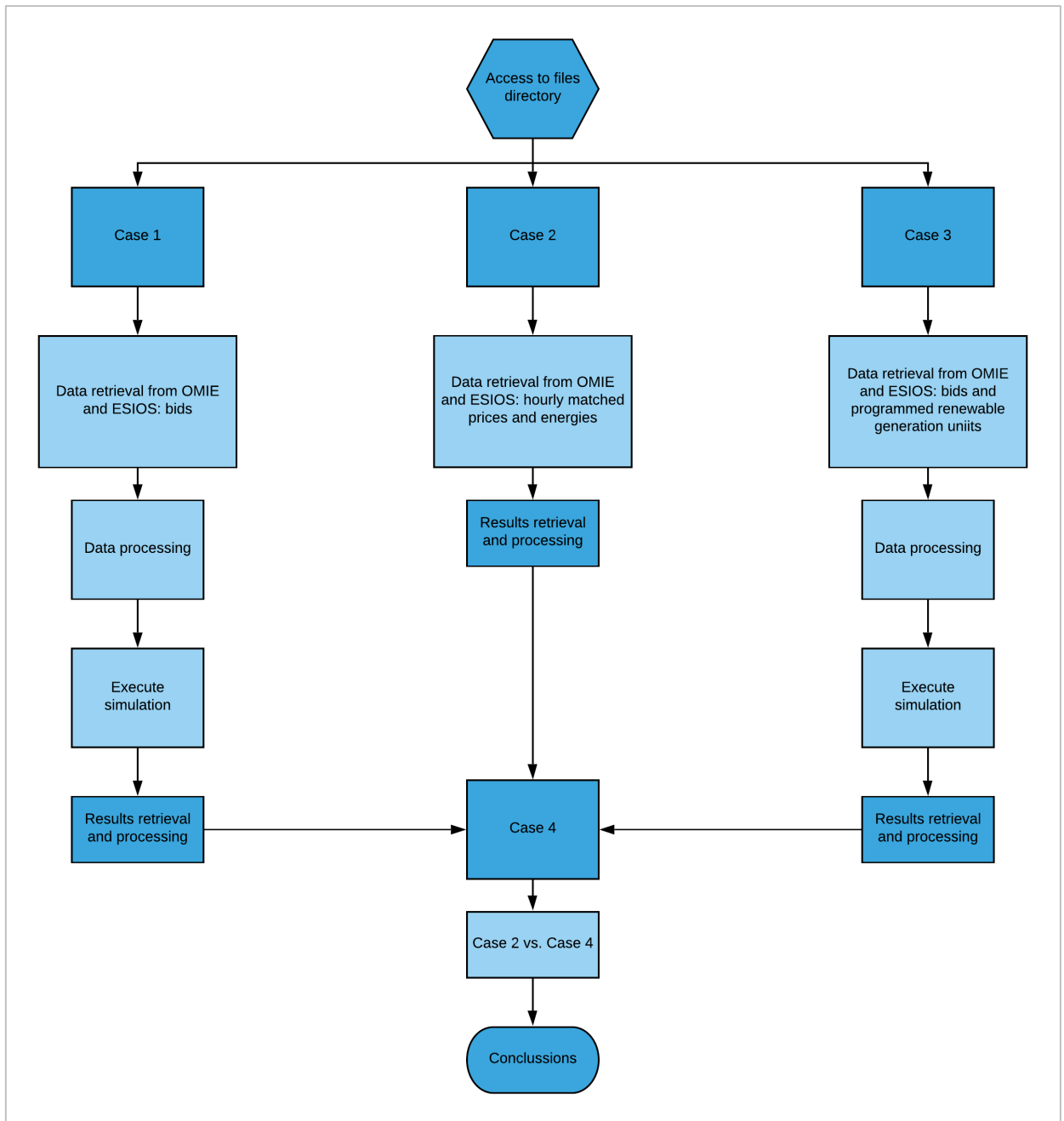


Figure 12: Flowchart describing the results retrieval process. SOURCE: Own compilation

In order to execute all these processes, only *Matlab*-based software tools are to be employed. Different algorithms, scripts and functions need to be implemented with the aim of performing the tasks needed. As the simulation explanation goes by, all the relevant details regarding these tools operation will be properly clarified and brought to the table.

Through the interactive and analytic tools supported by both *OMIE* and *ESIOS* websites, input data will be accessed and downloaded for its later processing. For cases 1 and 3, the same sale and purchase bids be considered (those of *Case 2*). Moreover, for *Case 3*, hourly renewable energy-generation units need to be taken into account, so that the sale bids auctioning renewable energy can be properly dismissed in the matching process.

For cases 1 and 3, once all the input data is properly processed, only the relevant information for the later analysis will be selected and disposed. This way, *Matlab* is able to work at its highest rates of efficiency and cleanliness. The scripts and functions are then executed to simulate the matching process, obtaining for every hour in the year reliable reproductions of the matched prices and energies that would have been obtained in the Daily Market operating in each of the different cases.

Finally, the results are properly stored and selected: only matched prices and energies obtained at the end of each yearly simulation are to be considered for the later analysis.

5.2. Assumptions made

The main assumption regarding the entire simulation of the matching process detailed in this paper is analytically described below.

$$k = \text{matchedPrice}_2 - \text{matchedPrice}_1 = \text{matchedPrice}_4 - \text{matchedPrice}_3$$

Thus, matchedPrice_2 is the hourly matched price of *Case 2* under Complex Bidding conditions while matchedPrice_1 is the hourly matched price obtained after the simulation of *Case 1*, taking only into account simple bids in the auctioning process. The energy mix considered for both cases is that of 2017, including renewable generation. The third part of the equality works symmetrically for cases 3 and 4 (2017's synthetic energy mix with no renewable generation).

However, it must be also said that for the simulation of *Case 3* and the later computation of *Case 4*, it is assumed that the installed power capacity in Spain is large enough to cover the demand that would have been supplied by renewables. This assumption could be said to be realistic, as the total energy auctioned to the market in an hourly basis is way larger than the market accepted volume of energy: there is supply enough to satisfy the whole demand.

Also, the *Base-Functioning Program (PBF)* was the official generation schedule employed to determine the hourly renewable production achieved in 2017. This schedule includes all the programmed-renewable generation to be negotiated in all spot markets and through the most recent bilateral contracts. It must be noted that, as explained in point 4, the participation in the Daily Market is mandatory for all the units not subjected to bilateral contracts. Thus, due to the impossibility of differentiating these energy blocks from each other, all renewable-programmed generation scheduled in the *PBF* has been included in the matching processes simulated in this paperwork. Therefore, even though share of energy traded in the most recent bilateral contracts is almost negligible regarding the overall production of renewables, this assumption must be taken into account when analysing the results reached.

Moreover, only data regarding the Spanish Daily Market operation during the year 2017 have been considered. However, the results obtained and conclusions reached in this paperwork do not aim to be extrapolated to any other period of time. The scope of the project has been focused on this year to show the effect renewable generation has nowadays over electricity prices.

5.3. Input data

All the input data used in this simulation is of public access and can be accessed through both OMIE and ESIOS websites. As previously stated on *Figure 12*, the execution of the model for both cases requires access to the aggregated curves of sale and purchase bids hourly auctioned to the 2017's Daily Market. These can be found in the form of daily text files at OMIE's website,

grouped in monthly folders stored in an outer one, named “*Zips mensuales con curvas agregadas de oferta y demanda del mercado diario incluyendo unidades de oferta*”. These folders need to be properly unzipped with the required software. The information collected in them dates back from 2001 and spans in time up to three months before the moment of the enquiry. Bids more recent than that are not yet published due to privacy issues.

The information available in each of this text files can be seen *Figure 13*, containing the following columns:

- *Hour (“Hora”)*: Ranging from 1 to 24
- *Date (“Fecha”)*: The date of the day specified in file’s name
- *Country (“País”)*: With three different possible values
 - *MI (Iberian Market)*: For bids in normal market conditions
 - *ES (Spain)*: For bids auctioned to the Spanish Market when market-splitting occurs
 - *PT (Portugal)*: For bids auctioned to the Portuguese Market when market-splitting occurs
- *Unit (“Unidad”)*: Not to be used
- *Bid Type (“Tipo Oferta”)*: With two different possible values
 - *C*: Referring to auctioned purchase bids
 - *V*: Referring to sale purchase bids
- *Energy (“Energía Compra/Venta”)*: Energy auctioned in its corresponding bid (MWh)
- *Price (“Precio Compra/Venta”)*: Price auctioned in its corresponding bid (€/MWh)
- *Auctioned/Matched (“Ofertada (O)/Casada (C)”)*: With two different possible values
 - *C*: Referring to matched bids. Not to be used
 - *O*: Referring to auctioned bids

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Hora;Fecha;País;Unidad;Tipo Oferta;Energía Compra/Venta;Precio Compra/Venta;Ofertada (O)/Casada (C);
1;01/01/2017;MI;ENDPC2;C;592,7;180,30;0;
1;01/01/2017;MI;ENDEC04;C;16,0;180,30;0;
1;01/01/2017;MI;ENDEC01;C;1.375,6;180,30;0;
1;01/01/2017;MI;EE21CEB;C;63,5;180,30;0;
1;01/01/2017;MI;EE21C01;C;1.592,2;180,30;0;
1;01/01/2017;MI;IBCUC01;C;1.334,1;180,30;0;
1;01/01/2017;MI;IGESC2;C;516,5;180,30;0;
1;01/01/2017;MI;ICLIC02;C;55,9;180,30;0;
1;01/01/2017;MI;IGESC01;C;2.064,2;180,30;0;
1;01/01/2017;MI;ONDRM09;C;6,3;180,30;0;
1;01/01/2017;MI;ONDRM10;C;0,7;180,30;0;
1;01/01/2017;MI;GNSUCEB;C;0,1;180,30;0;
1;01/01/2017;MI;EDPUC2;C;647,1;180,30;0;
1;01/01/2017;MI;GEDPGC2;C;2.536,8;180,30;0;
1;01/01/2017;MI;HCGC01;C;1.518,6;180,30;0;
1;01/01/2017;MI;GGASNC1;C;2.795,6;180,30;0;
1;01/01/2017;MI;GEDFTC1;C;75,0;180,30;0;
1;01/01/2017;MI;GNCOC02;C;93,0;180,30;0;
1;01/01/2017;MI;HISPC01;C;0,1;180,30;0;

```

Figure 13: Example of source file containing hourly sale and purchase bids for a given day. SOURCE: OMIE.

Additionally, for the simulation of *Case 3* it is required to determine the 2017 programmed renewable-energy generation so that it can be dismissed from the auctioning process. As stated in point 5.2, the *Base Functioning Program (PBF)* schedules energy production to be negotiated at the Day-ahead Market and through bilateral contracts. This way, by accessing to the detail of its operation, this planning can be known. This information can be found at *ESIOS* website, hosted by *REE*, and can be interactively visualized through its recently-implemented analysis software tool shown in *Figure 14*. By means of selecting the desired period of time to be studied, different files containing the programmed yearly energy to be generated by each kind of renewable technology can be exported in *CSV*, *EXCEL* and *JSON* formats.



Figure 14.: Example of ESIOS's analysis tool for the PBF biomass programmed generation. SOURCE: ESIOS

The considered renewable-generation technologies in this paperwork were those contained in the old *Special Regime* stated in *Law 54/1997*:

- Biomass Energy
- Wind Energy
- Mini-Hydraulic Energy
- Photo-Voltaic energy
- Solar Thermo-Electric Energy

And so were considered other renewable-generation technologies, not included into the *Special Regime*:

- Biogas Energy
- Oceanic and Geothermal Energy
- Other Renewables

Once the files have been properly exported, its content appears as in *Figure 15*, including the following columns:

- *ID*: Not to be used
- *Name*: The kind of renewable-generation technology specified in file's name
- *Geoid*: Not to be used
- *Geoname*: Not to be used
- *Value*: Amount of energy hourly generated

- *Datetime*: Hourly date of the corresponding generation

id	name	geoid	geoname	value	datetime
22	Generación programada PBF Biogás			93,3	2017-01-01T00:00:00+01:00
22	Generación programada PBF Biogás			91,9	2017-01-01T01:00:00+01:00
22	Generación programada PBF Biogás			91,9	2017-01-01T02:00:00+01:00
22	Generación programada PBF Biogás			92	2017-01-01T03:00:00+01:00
22	Generación programada PBF Biogás			91,9	2017-01-01T04:00:00+01:00
22	Generación programada PBF Biogás			84,2	2017-01-01T05:00:00+01:00
22	Generación programada PBF Biogás			84,6	2017-01-01T06:00:00+01:00
22	Generación programada PBF Biogás			83,2	2017-01-01T07:00:00+01:00
22	Generación programada PBF Biogás			81,2	2017-01-01T08:00:00+01:00
22	Generación programada PBF Biogás			80,9	2017-01-01T09:00:00+01:00
22	Generación programada PBF Biogás			86,6	2017-01-01T10:00:00+01:00
22	Generación programada PBF Biogás			88,6	2017-01-01T11:00:00+01:00
22	Generación programada PBF Biogás			88,9	2017-01-01T12:00:00+01:00
22	Generación programada PBF Biogás			86,7	2017-01-01T13:00:00+01:00
22	Generación programada PBF Biogás			87,3	2017-01-01T14:00:00+01:00
22	Generación programada PBF Biogás			89,6	2017-01-01T15:00:00+01:00
22	Generación programada PBF Biogás			89,7	2017-01-01T16:00:00+01:00

Figure 15: Example of source file containing hourly biogas programmed energy generation. SOURCE: ESIOS.

In order to compare the results obtained for *Case 4* (computed out of the outputs from the simulation of cases 1 and 3) with those of *Case 2*, data collections containing the actual matched prices and energies in the 2017's Daily Market operation need to be also accessed. Again at *ESIOS* website, files containing the hourly matched energies can be exported by means of using its analysis tool as shown in *Figure 16*.

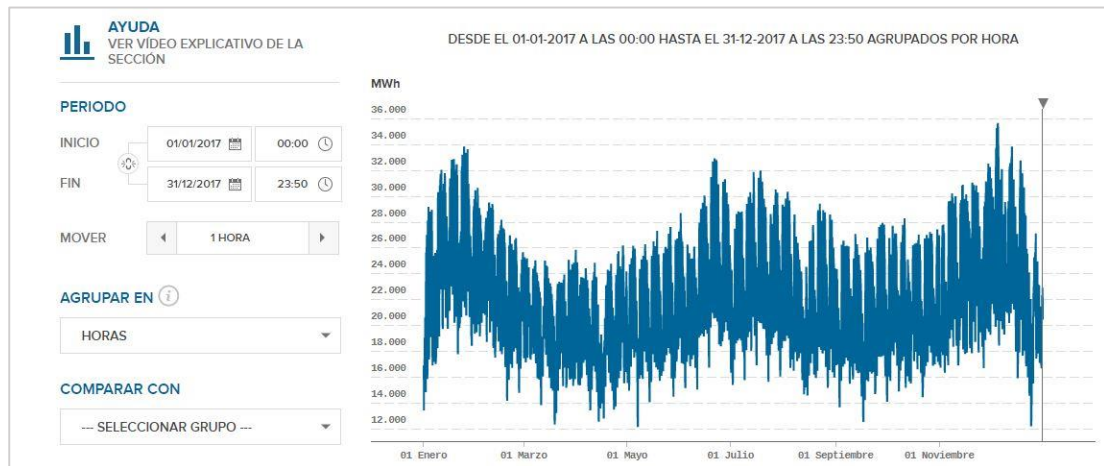


Figure 16: ESIOS's analysis tool for the hourly matched energies at the 2017 daily SPOT market. SOURCE: ESIOS.

Once the file has been properly exported, its content appears as in *Figure 17*, including the following columns:

- *ID*: Not to be used
- *Name*: Not to be used
- *Geoid*: Not to be used

- *Geoname*: Not to be used
- *Value*: Hourly matched energy
- *Datetime*: Hourly date of the corresponding energy

id	name	geoid	geoname	value	datetime
602	Energía asignada en Mercado SPOT Diario España			16.887,50	2017-01-01T00:00:00+01:00
602	Energía asignada en Mercado SPOT Diario España			15.876,40	2017-01-01T01:00:00+01:00
602	Energía asignada en Mercado SPOT Diario España			14.549,90	2017-01-01T02:00:00+01:00
602	Energía asignada en Mercado SPOT Diario España			13.483,90	2017-01-01T03:00:00+01:00
602	Energía asignada en Mercado SPOT Diario España			14.506,90	2017-01-01T04:00:00+01:00
602	Energía asignada en Mercado SPOT Diario España			15.201,80	2017-01-01T05:00:00+01:00
602	Energía asignada en Mercado SPOT Diario España			15.339,80	2017-01-01T06:00:00+01:00
602	Energía asignada en Mercado SPOT Diario España			15.459,80	2017-01-01T07:00:00+01:00
602	Energía asignada en Mercado SPOT Diario España			15.780,60	2017-01-01T08:00:00+01:00

Figure 17: Example of source file containing hourly matched energies at 2017 daily SPOT market. SOURCE: ESIOS.

Similarly, files containing the hourly matched prices can be also exported by means of using again *ESIOS*'s analysis tool as shown in *Figure 18*:

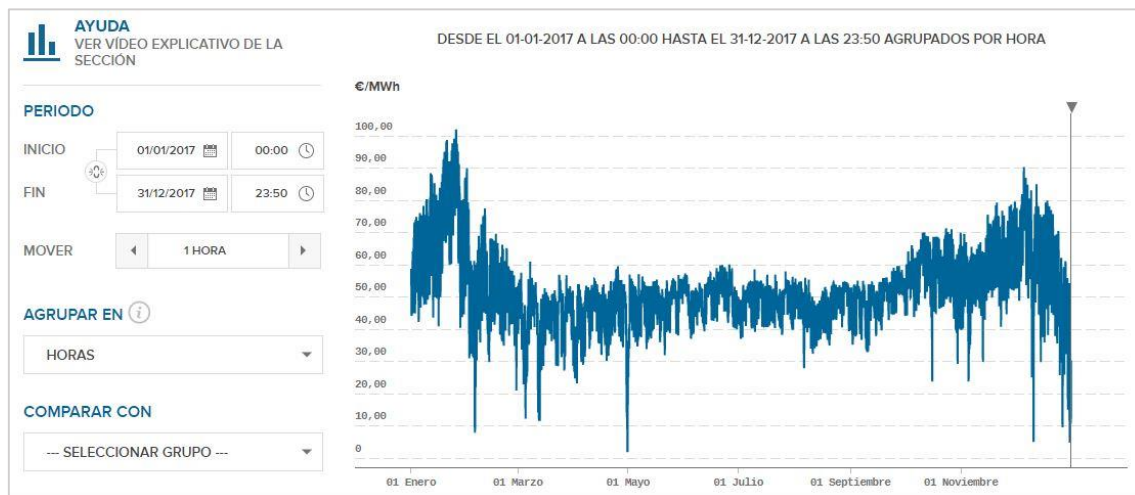


Figure 18: ESIOS's analysis tool for the hourly matched prices at the 2017 daily SPOT market. SOURCE: ESIOS.

Once the file has been properly exported, its content appears as in *Figure 19*, including the following columns:

- *ID*: Not to be used
- *Name*: Not to be used
- *Geoid*: Not to be used
- *Geoname*: Not to be used
- *Value*: Hourly matched price
- *Datetime*: Hourly date of the corresponding price

id	name	geoid	geoname	value	datetime
600	Precio mercado SPOT Diario	3	España	58,82	2017-01-01T00:00:00+01:00
600	Precio mercado SPOT Diario	3	España	58,23	2017-01-01T01:00:00+01:00
600	Precio mercado SPOT Diario	3	España	51,95	2017-01-01T02:00:00+01:00
600	Precio mercado SPOT Diario	3	España	47,27	2017-01-01T03:00:00+01:00
600	Precio mercado SPOT Diario	3	España	45,49	2017-01-01T04:00:00+01:00
600	Precio mercado SPOT Diario	3	España	44,5	2017-01-01T05:00:00+01:00
600	Precio mercado SPOT Diario	3	España	44,5	2017-01-01T06:00:00+01:00
600	Precio mercado SPOT Diario	3	España	44,72	2017-01-01T07:00:00+01:00
600	Precio mercado SPOT Diario	3	España	44,22	2017-01-01T08:00:00+01:00
600	Precio mercado SPOT Diario	3	España	45,13	2017-01-01T09:00:00+01:00
600	Precio mercado SPOT Diario	3	España	46,23	2017-01-01T10:00:00+01:00
600	Precio mercado SPOT Diario	3	España	47,91	2017-01-01T11:00:00+01:00
600	Precio mercado SPOT Diario	3	España	49,57	2017-01-01T12:00:00+01:00
600	Precio mercado SPOT Diario	3	España	48,69	2017-01-01T13:00:00+01:00
600	Precio mercado SPOT Diario	3	España	47,2	2017-01-01T14:00:00+01:00

Figure 19: Example of source file containing hourly matched prices at 2017 daily SPOT market. SOURCE: ESIOS.

5.3.1. Data processing

Once the input data has been properly selected, it is essential to properly process it. The first issue to take care of, is the files format. As seen before, there are daily text files containing the published sale and purchase bids. The name of these files is a generic one associated to its date and, moreover, it has been added a digit at the end of it. This way, they all have the following form: “*curva_pbc_uof_yyyymmdd.I*”, being “*I*” the extension of the file.

In order to adequate the 365 daily files format into another readable for the *Matlab* software, a code is implemented to rename all these files and convert them into *DAT*-files: the script “*rename_Files*”. This script erases the “*I*” after the dot and then adds the “*dat*” extension. The execution of this script is represented below through a flow-chart diagram (Figure 20).

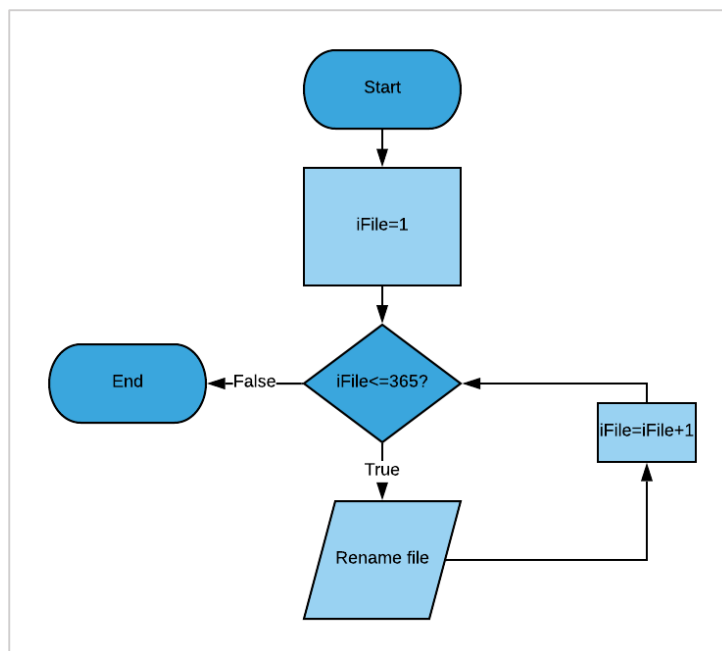


Figure 20: Flowchart describing the operation of “*rename_Files*” script. SOURCE: Own compilation.

Once all input files are readable and manageable for *Matlab*, for cleansing and operational reasons, input data still needs further processing. To do so, scripts “*matching_Ren*” (*Case 1*) and “*matching_NO_Ren*” (*Case 3*) are written. The code implemented in them is embed into a loop which executes the following steps in each iteration, so that daily files are accessed and modified one by one.

First of all, empty columns and rows are deleted. Also, leading rows containing the headers are removed so that only relevant data remains in the file. Afterwards, by means of logical indexing, matched bids and bids auctioned to the Portuguese Market when market-splitting occurs are also deleted, so that they are not taken into account in the bidding process simulation. Subsequent to this, columns containing numerical data saved as *string* need to be properly converted to *double*, where previously the dots and commas standing for thousands and decimals have been switched.

Again by means of logical indexing, vectors containing prices and energies bid to the Daily Market are generated. Different vectors are created for purchase and sale bids. Later on, these are grouped hourly into *supply* and *demand* matrices, which are then used as input parameters for the calling of the functions “*Fmatching_Ren*” (*Case 1*) and “*Fmatching_NO_Ren*” (*Case 3*).

5.4. Case 1: Matching with renewable generation

In the script “*matching_Ren*”, before calling the function “*Fmatching_Ren*” an inner loop of 24 iterations is implemented on the code in order to call the matching function hourly. However, there is still need to solve the problems associated to the two time changes that take place over the year. Calendar of 2017 states that time changes on this year took place on March 26th and October 29th; which correspond to days 85 and 302 of the year, respectively.

Thus, manually, one hour must be subtracted to the 85th day and another hour must be added to the 302th. To do so, two additional loops of 23 and 25 iterations are implemented. By means of using conditional commands, these two loops are only accessed when the counter of the outer loop matches with the condition statement, so that code keeps running through the main loop if *FALSE*. Description of the operation-flow of the above-mentioned script is shown below in *Figure 21*.

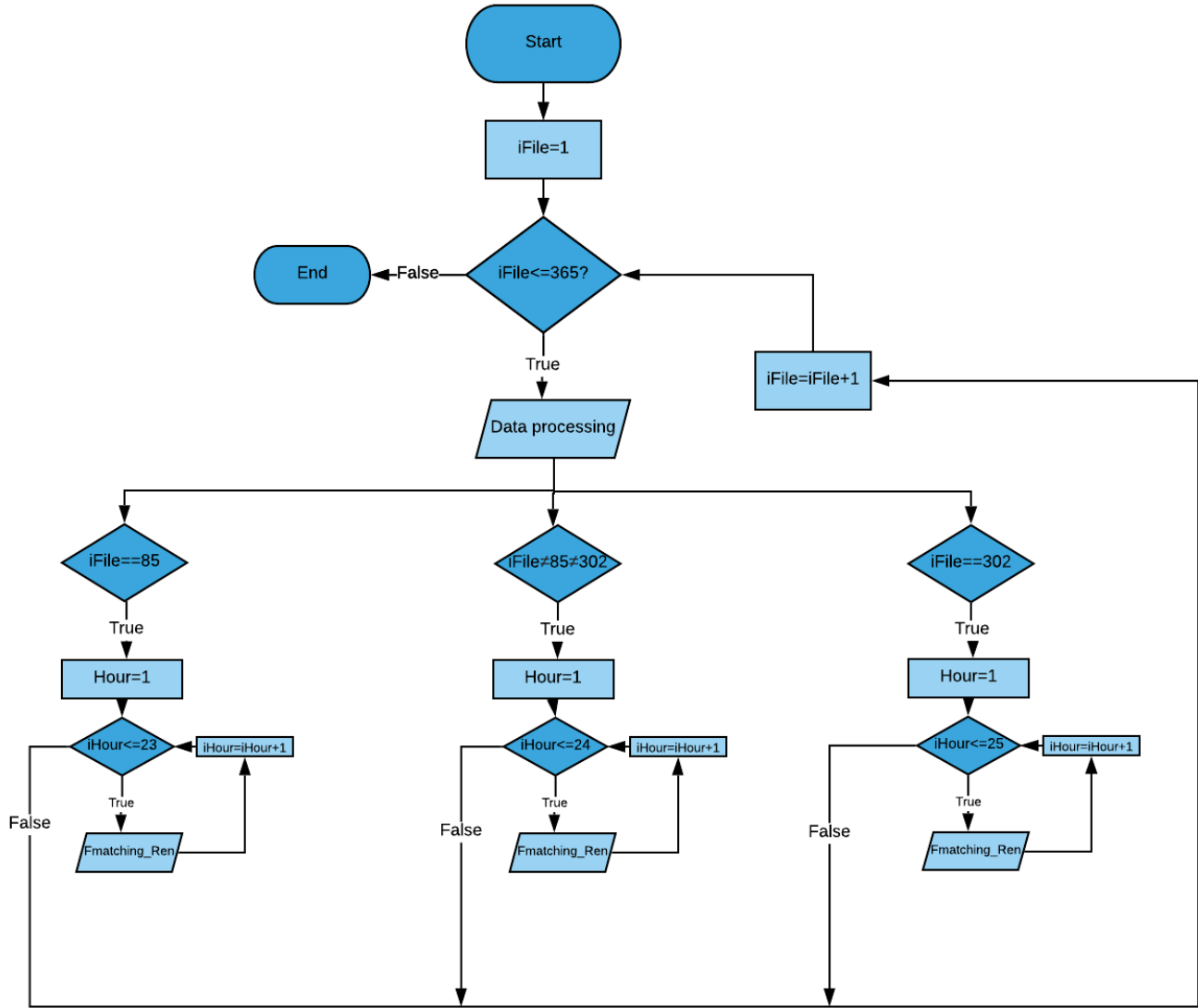


Figure 21: Flowchart describing the operation of “matching_Ren” script. SOURCE: Own compilation.

Thus, the function “*Fmatching_Ren*” simulates the hourly matching process that would take place in the Daily Market. The operation of this function is detailed as follows.

First of all, the matrixes containing the hourly bids need to be sorted by price: sale bids (*supply* matrix) are sorted from least to greatest and purchase bids (*demand* matrix) from greater to lower price. Once they have been sorted, an accumulated sum of the energies column for each of the matrixes must be performed.

Later, the function seeks element by element, in ascending order, the first position at which the *supply* matrix (*iofe*) has a larger energy than the *demand* matrix at the given position (*idem*). The seeking process is iterated until the price of the *supply* matrix at position *iofe* is greater than the price of the *demand* matrix at position *idem*. Once this condition is fulfilled, matched prices and energies are settled. Performance of the function “*Fmatching_Ren*” can be seen below in Figure 22.

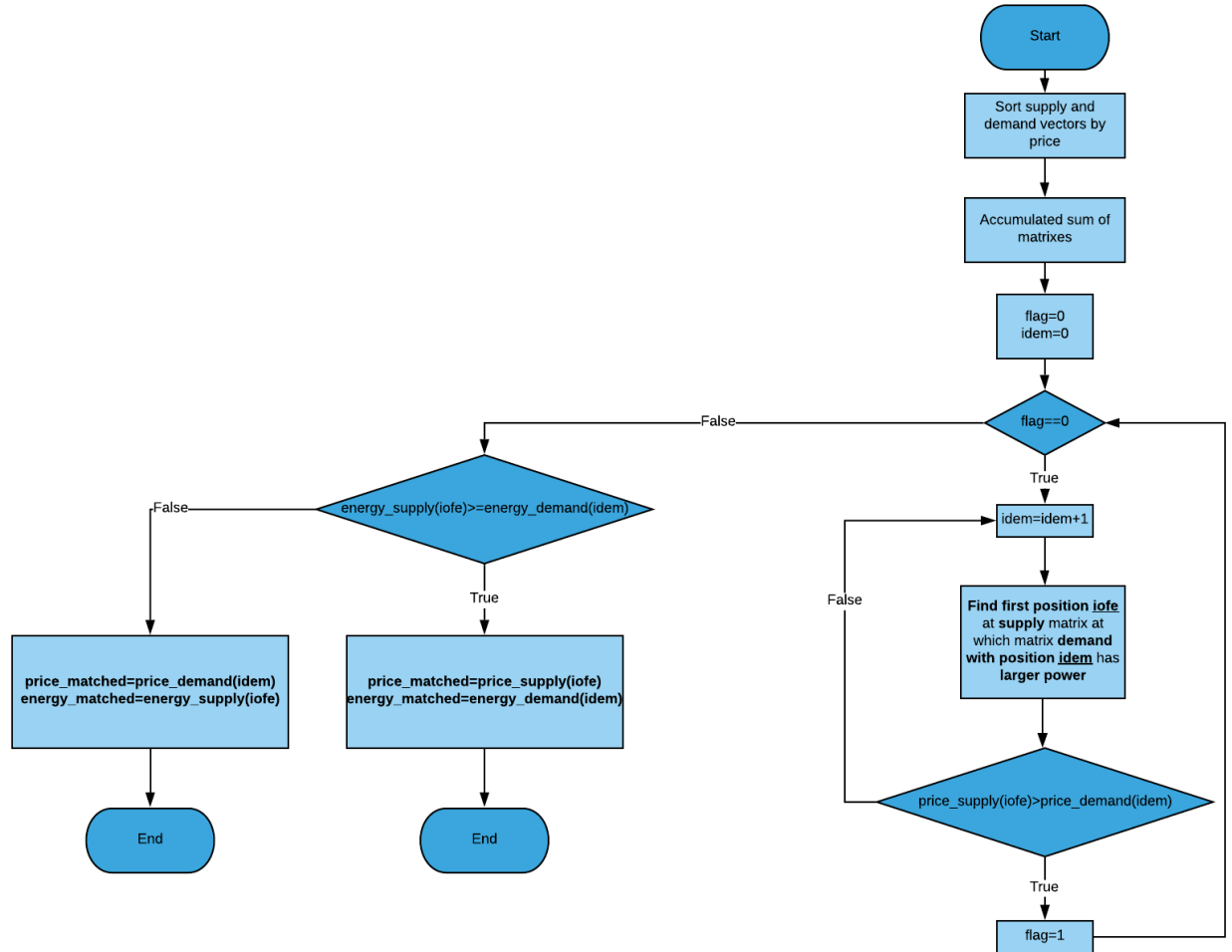


Figure 22: Flowchart describing the operation of “Fmatching_Ren” function. SOURCE: Own compilation.

Hourly matched process and energies are saved in two 1-by-8760 vectors (*matchedPriceAcc* and *matchedQuantityAcc*) for later study.

5.5. Case 3: Matching without renewable generation

The simulation of the matching process for *Case 3* takes place through the execution of the script “*matching_NO_Ren*”. The code written on it is very similar to the one used in “*matching_NO_Ren*” (*Case 1*). The only difference between both scripts is the dismissal of the energy bid from renewable-generation units from the whole matching process (*Case 3*).

Thus, a new piece of code is implemented into the script “*matching_NO_Ren*”, so that renewable-generated energy auctioning to the matching process can be properly identified. However, files containing the scheduled hourly renewable generation by the *PBF* only include the hours of the year with non-zero renewable generation. Consequently, it is necessary to embed a new inner loop at the beginning of the script. In each iteration, this loop accesses to the file’s directory and reads one file at a time, writing vectors containing in each element the hourly energy generated. If any date leaps appear during this process, zero rows are then added to the vector in order for it to be consistent with the size of the remaining data collections in the simulation, obtaining the vector *quantityGenRenAcc*.

Once all the files are correctly processed and translated into vectors, these are summed between them in order to compute the total generation of all renewable technologies. From then on, the script “*matching_NO_Ren*” works the same way “*matching_Ren*” does. The only other difference with respect this script is that *quantityGenRenAcc* is declared as an input parameter when calling the function “*Fmatching_NO_Ren*”, together with the *supply* and *demand* matrixes hourly indexed.

The function “*Fmatching_NO_Ren*” is written as “*Fmatching_Ren*” (*Case 1*) but has been added a new piece of code. Before the matching algorithm is executed, the renewable generation needs to be subtracted to the *supply* matrix. To do so, the function seeks the first element of the matrix at which the accumulated energy is greater than the value of *quantityGenRenAcc* at the given hour. Once this element position is found, the supply matrix is re-sized: all matrix elements with index smaller than the position found are deleted. After implementing this modification on the code, the function works the same way as that of used in the simulation of *Case 1*.

5.6. Results analysis

Once the two main scripts have been completely executed, the resulting vectors containing hourly matched prices and energies are saved into the following *MAT*-files:

- Case 1: *matchedPrice&Quantity_Ren.mat*
- Case 3: *matchedPrice&Quantity_NoRen.mat*

Now, these results need to be integrated with those included in the data collections as actual matched prices and energies in the 2017’s Daily Market (*Case 2*), accessed through *ESIOS*’s website. The matched prices and energies collected in this files were the ones settled as official by the Market Operator. Thus, there can be no doubt that real operation conditions were taken into account during their settling, so that complex conditions were applied and considered.

In order to read them and save the desired values in manageable data structures for the *Matlab* software, a new script is implemented: “*load_OMIE_files*”. This script saves two different vectors for hourly matched prices and quantities which are later stores into another *MAT*-file:

- Case 2: *matchedPrice&Quantity_OMIE*

Once all the output data is correctly stored, we can proceed to execute the script “*compute_Savings*”, in order to compute *Case 4*. This script loads all these data structures and renames them with the aim of enabling an efficient and precise data manageability for the user. Thus, the remaining vectors containing hourly matched prices and energies are the following:

- a) Case 1:
 - *matchedPrice_Ren_S*
 - *matchedQuantity_Ren_S*
- b) Case 2:
 - *matchedPrice_Ren_CC*
 - *matchedQuantity_Ren_CC*
- c) Case 3:
 - *matchedPrice_NoRen_S*
 - *matchedQuantity_NoRen_S*

Then, as stated in point 5.2, the difference between *Case 2* and *Case 1* prices (k) and energies (j) are computed as seen below in *Figure 23*:

```
k=matchedPrice_Ren_CC-matchedPrice_Ren_S;
j=matchedQuantity_Ren_CC-matchedQuantity_Ren_S;
```

Figure 23: Piece of code from script “compute_Savings” computing “ k ” and “ j ”. SOURCE: Own compilation.

Afterwards, the final hourly prices and energies that would have been matched in an energy mix with no renewable generation and under Complex Bidding conditions (*Case 4*) are calculated. These are obtained by means of adding vectors k and j to the prices and energies obtained after the simulation of *Case 3*, respectively.

$$matchedPrice_4 = k + matchedPrice_3$$

$$matchedEnergy_4 = j + matchedEnergy_3$$

The resultant vectors are named as below, in order to be consistent with the naming of the remaining ones:

d) Case 4:

- $matchedPrice_NoRen_CC$
- $matchedQuantity_NoRen_CC$

Where; “*CC*” stands for *Complex Conditions*, “*S*” for *Simple* ones, “*Ren*” for the current energy mix and “*NoRen*” for the current energy mix with no renewable generation.

In order to make sure that the simulation of cases 1 and 3 has been successful and consistent, the results obtained are contrasted with those published by *OMIE*. On its website, by clicking on a tab called “*RESULTADOS DEL MERCADO*”, an analysis tool is displayed. This tool shows the hourly aggregated curves of simple and complex sale bids, and so does for purchase ones. Thus, we can check that the results obtained after the simple matching simulated in *Case 1* converge with those shown by the tool. Even though the results obtained from the simulation of *Case 3* cannot be checked (there are no such things as hourly simple matching bid curves without renewables displayable by the tool), we can rely on them as the code implemented to reach them is symmetrically similar as that of *Case 1*.

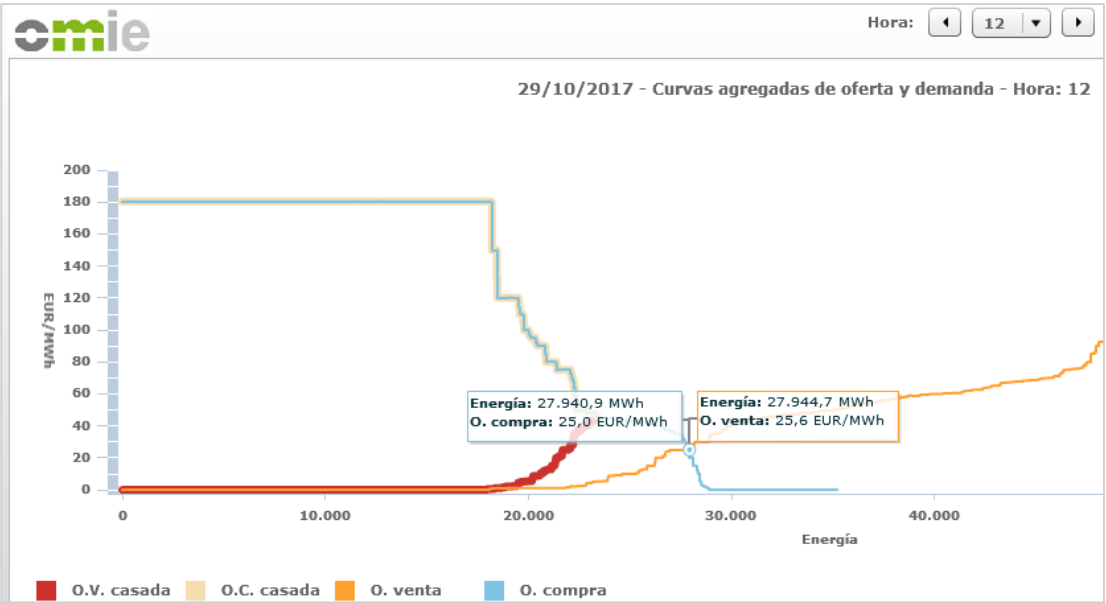


Figure 24: OMIE’s online tool displaying hourly aggregated curves of purchase and sale bids. SOURCE: OMIE.

By means of comparing *Figure 24* and *Figure 25*, it can be stated that results are consistent and coherent:

Variables - matchedQuantityAcc						
matchedPriceAcc						
1x8760 double						
	7231	7232	7233	7234	7235	7236
1	25	20	21	25	25.6000	25
2						
3						
4						
<						
matchedQuantityAcc						
1x8760 double						
	7231	7232	7233	7234	7235	7236
1	2.3238e+04	2.3516e+04	2.4323e+04	2.6301e+04	2.7941e+04	2.8698e+04

Figure 25: Matched price and energy of Case 1 for the given date detailed in Figure 24. SOURCE: Own compilation.

Results are consistent even in hours under market-splitting conditions, as seen in *Figure 26* and *Figure 27*:

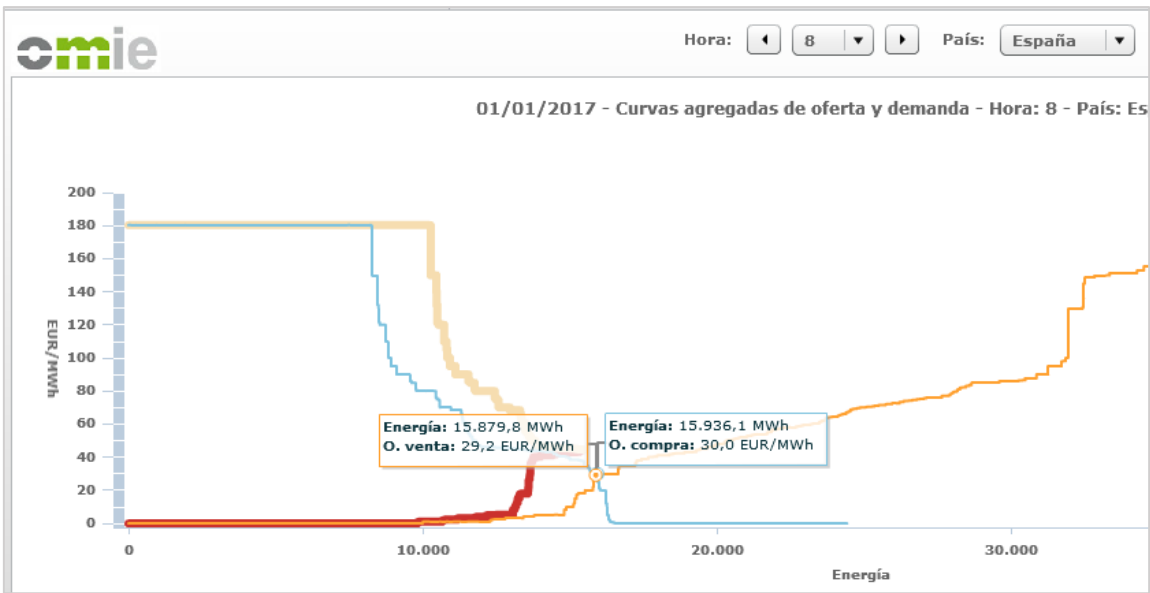


Figure 26: OMIE’s online tool displaying hourly aggregated curves of purchase and sale bids under market-splitting conditions. SOURCE: OMIE.

Variables - matchedQuantityAcc				
matchedPriceAcc ✕				
1x8760 double				
	7	8	9	10
1	35	30	5.1300	30
2				
3				
4				
<				
matchedQuantityAcc ✕				
1x8760 double				
	7	8	9	10
1	1.5257e+04	1.5989e+04	1.6602e+04	2.3596e+04
2				
3				
4				

Figure 27 Matched price and energy of Case 1 for the given date detailed in Figure 26. SOURCE: Own compilation.

5.6.1. Market prices lowering and savings increment

Also, in script “compute_Savings”, savings are computed as sum of the hourly difference between products of energies and prices. Thus:

- Cases 1 and 3: *savings_Yearly_S*
- Cases 2 and 4: *savings_Yearly_CC*

Consequently, the average lowering on *pool's* price is computed as the quotient between these savings and the total amount on energy traded hourly in 2017 Daily Markey, computed as the accumulated sum of the matched energy vector of *Case 2*. This case is used as baseline scenario because, even though the results have been proved to be consistent, it is still the data collection with the smallest degree of uncertainty, as it is directly taken from OMIE's files. Then:

- Cases 1 and 3: p_{low_S}
- Cases 2 and 4: p_{low_CC}

So, finally the results obtained are the following:

<i>Magnitude</i>	<i>Units</i>	<i>Value</i>
<i>Underselling of pool's price (Complex Bidding)</i>	€/MWh	7,47
<i>Total savings on pool's price (Complex Bidding)</i>	million €	1.478
<i>Underselling of pool's price (Simple Bidding)</i>	€/MWh	10,54
<i>Total savings on pool's price (Simple Bidding)</i>	million €	2.740

Table 1: Table collecting the results obtained after the execution of the implemented code. SOURCE: Own compilation.

6. COMPARATIVE ANALYSIS VS. APPA REPORT 2017

In order to properly compare both results, it is needed to adjust the studied scenario to that of published in [1]. In that report, the equivalent cases 3 and 4 simulated have been studied from a different starting point. Thus, on APPA's report the only renewable-generation technologies dismissed in the bidding process were those included in the *Special Regime*, being:

- Biomass Energy
- Wind Energy
- Mini-Hydraulic Energy
- Photo-Voltaic energy
- Solar Thermo-Electric Energy

Thus, a new script “*matching_NO_Ren_APPA*” is implemented to simulate *Case 3*, with the above-mentioned conditions. The savings computation is also performed in another script (“*compute_Savings_APPA*”) so that results are not overwritten and the different codes can be easily and quickly re-executed.

Obtaining, for the newly studied conditions, the following results:

Magnitude	Units	Value
<i>Underselling of pool's price (Complex Bidding)</i>	€/MWh	6,97
<i>Total savings on pool's price (Complex Bidding)</i>	million €	1.379
<i>Underselling of pool's price (Simple Bidding)</i>	€/MWh	9,94
<i>Total savings on pool's price (Simple Bidding)</i>	million €	2.584

Table 2: Results obtained after the execution of the codes stated in 6.1. SOURCE: Own compilation.

Which contrast with those published in the APPA 2017 Report:

Magnitude	Units	Value
<i>Underselling of Pool's price</i>	€/MWh	10,23
<i>Total savings on Pool's price</i>	million €	2.584

Table 3: Table condensing the results of the matching simulated in the APPA report 2017. SOURCE: APPA

By means of comparing all results, at first sight, it can be easily observed the noticeable similarity between those simulated with Simple Bidding (cases 1 and 3) and the ones published by APPA. Contrasting both results, it can be stated that the simulated results converge almost

totally with those published standing for the underselling of *pool*'s price (97% of similarity) and totally for the total savings on *pool*'s price (100%).

This fact provides for thought that there is, at least, a relevant chance that this report may have built part of its overall macroeconomic analysis under the assumption of Simple Bidding conditions. It must be also noted that no mention to the kind of bids used as starting point for the simulation performed is made nowhere in the report, not even in the chapter devoted to the analysis of the impact of renewables on Daily Market's operation ("*CAPÍTULO 6: Retribución y ahorros de las energías renovables*").

Nevertheless, in order to give more consistency to the drawn of conclusions process, a further analysis is carried out. The focus is now placed over the historical results published by the report on past editions. *Figure 28* shows the evolution of the underselling of *pool*'s price published in the last eight APPA reports.



Figure 28: Historical results of *pool*'s price underselling published by APPA throughout 2010-2017. SOURCE: APPA.

Thus, putting these in contrast with those published by OMIE (*Figure 29*), we can deduce the proportional savings on *pool*'s price.

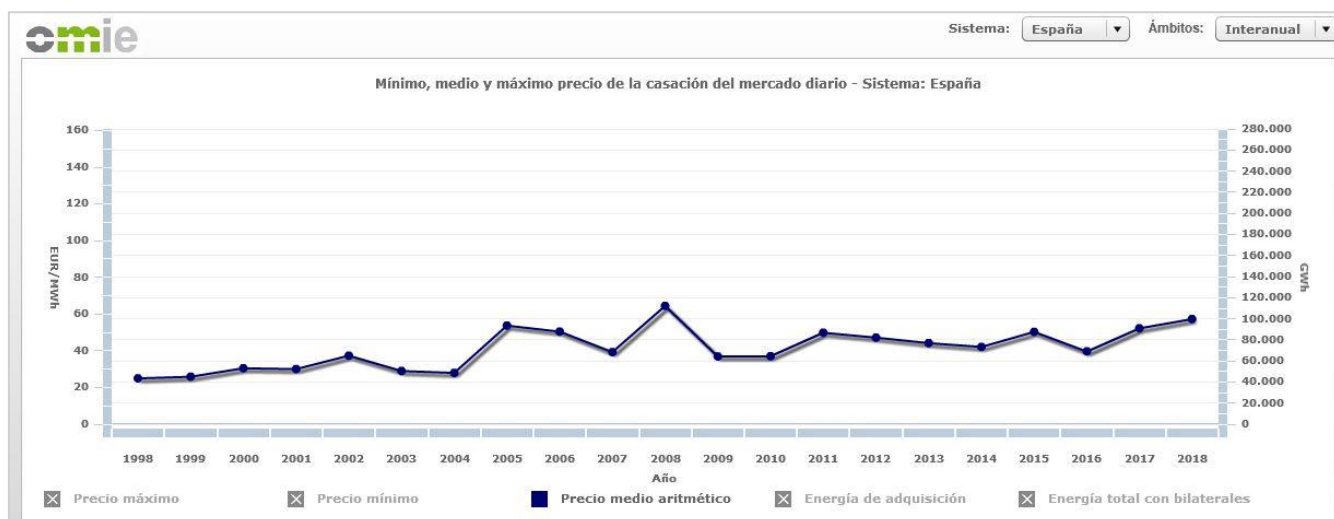


Figure 29: OMIE's online tool displaying mean hourly matched prices at the *pool* yearly. SOURCE: OMIE.

Table 4 shows, graphically, the depressing effect of renewables integration over electricity prices computed by APPA.

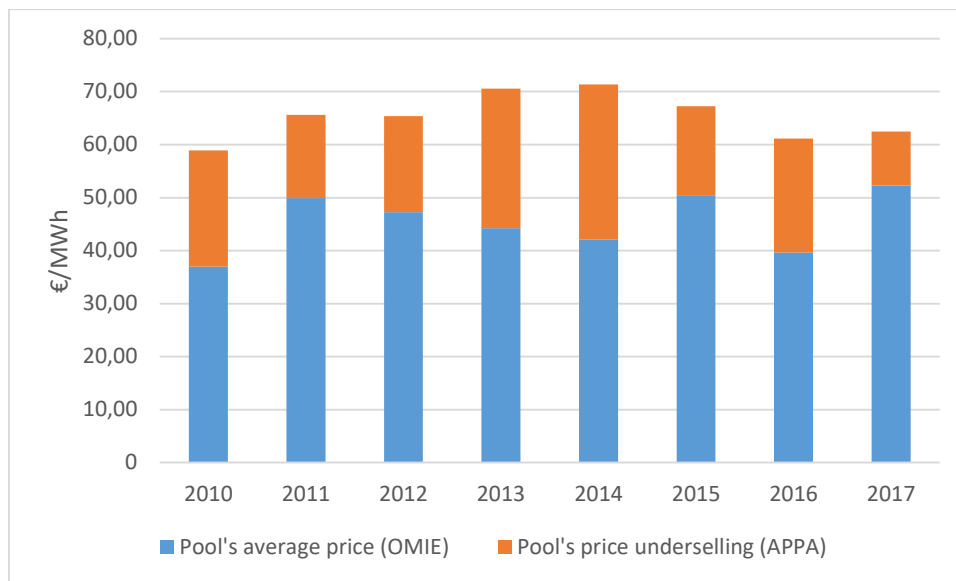


Table 4: Graphical representation of renewables underselling during 2010-2017. SOURCE: OMIE, APPA and own compilation.

Also, we can found at [6] the computed yearly renewable generation in Spain, being this information fairly interesting when contrasting figures. However, we must take into account that, even though its effect in our calculations is moderated, these figures include also biogas, oceanic, geothermal and renewable waste.

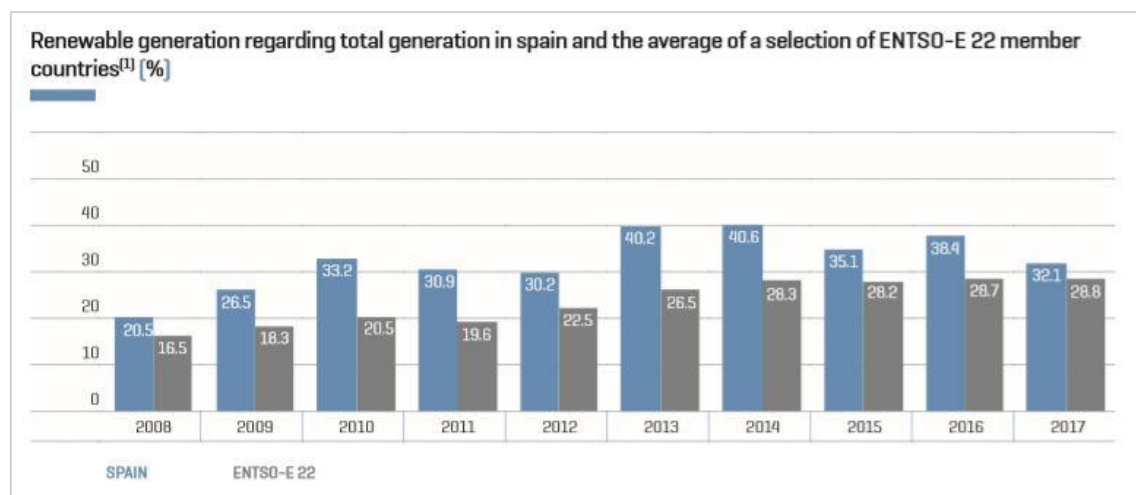


Figure 30: Weight of renewable generation in total generation. SOURCE: REE [6].

By means of integrating all these figures, relevant conclusions can be reached. Table 5 shows the relationship between the cheapening of market prices resulting from the *merit-order effect* and the share of renewable generation regarding overall generation.

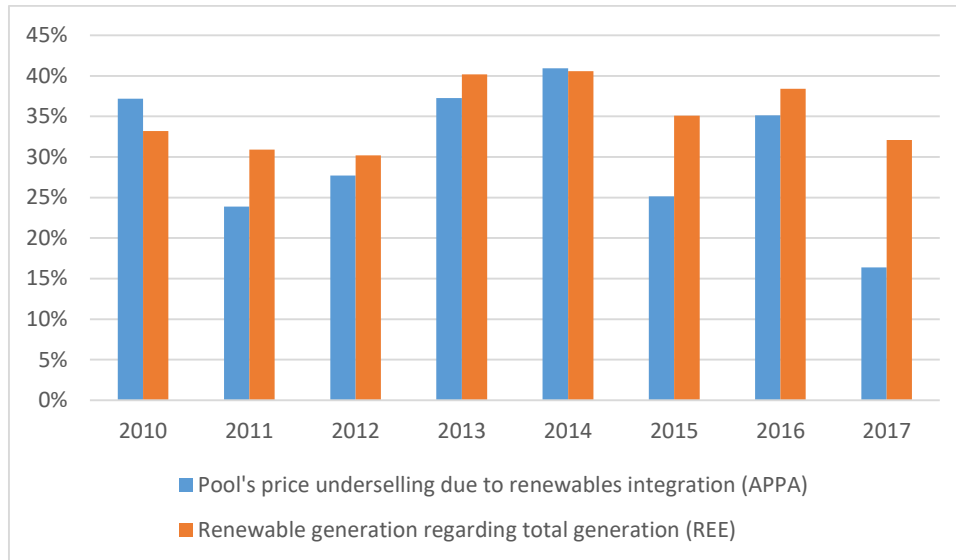


Table 5: Renewables prices underselling vs renewables generation. SOURCE: APPA, REE [6], and own compilation.

From the above it can be noticed that, in general terms, the prices underselling follows the yearly trend settled by the integration of renewables in the energy mix. However, and especially noticeable in the last years, it can be seen how the progressive increment on renewable generation causes prices' volatility to considerable rise. This fact is better shown in Table 6.

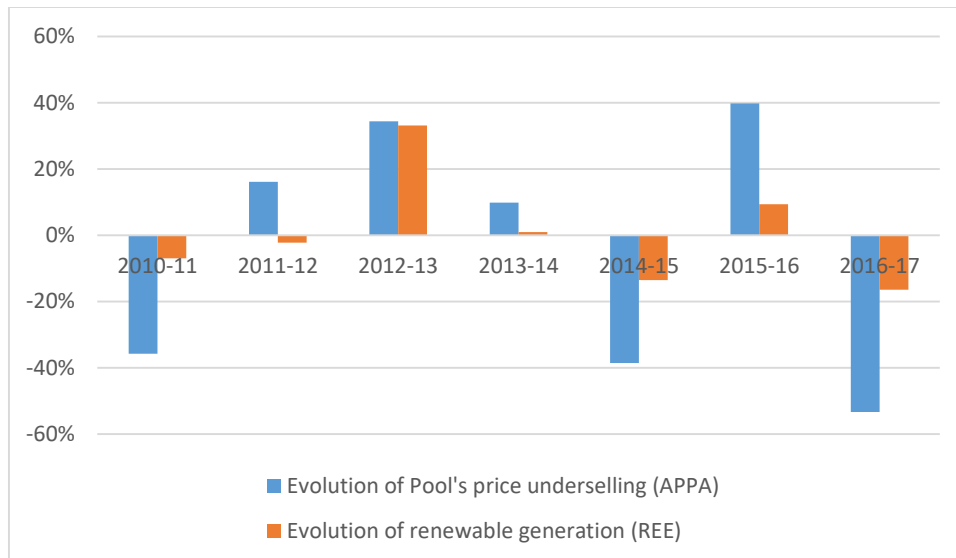


Table 6: Evolution of renewables prices underselling vs. renewables generation. SOURCE: APPA, REE [6] and own compilation.

This volatility on prices is mainly associated, as explained in the concluding remarks of [22], to the progressive world-wide increment on fuel prices. Thus, APPA report gathers the general trend of the depressive effect of renewables integration on *pool* prices: their results are coherent with the current market situation. Furthermore, the sudden falling of the prices cheapening in 2017 is mainly due to the severe droughts that took place in this year, which negatively affected hydroelectric power generation [1], [6]. This event, which goes completely along the line of rising prices volatility, drove fuel-based generation units to flexibly increase their generation output, using growing expensive fuels in an unpredicted way. Thus, fuel-based generators, in order to pay-off this circumstantially bigger marginal costs, had to auction sale bids

to the energy market at higher prices. This fact, made the underselling on prices generated by the renewables integration (which is limited whatsoever) less noticeable.

Thus, it can be said that even though the simulation results published seem consistent and coherent with the current reality surrounding the energy sector, no evidence is provided to confirm that these were calculated under Complex Bidding conditions. If this was true, the simulation with complex bids would have settled the *pool's* prices cheapening lower by 32% than the published one. This may also have implications on the further analysis performed on the report, as a substantial part of its thesis arguing to increase public spending on renewables is based on the argument that the prices reduction associated to its integration pays-off the renewable energy remuneration system settled by the Government. Under complex Bidding conditions, this may not be true. However, in the report this last analysis is performed over a period of time spanning from 2010 to 2017. As the only comparable sample of information provided in this report dates from year 2017, there is not enough data to comparatively analyse the mentioned fact in a rigorous way.

Moreover, it has to be stated that to properly analyse this paying-off, the savings to be compared with the specific retribution to renewables must be those generated to the end-users. They are the ones who publicly contribute to the public treasury through specific taxation in order to raise the funds to be devoted to these activities. In the *APPA* report, the only savings computed are the ones generated in the Daily Market operation. However, it has to be said that for the studied year, the stated specific remuneration received by renewable generation units published in *APPA* report was of 5.674 million €, which completely converges with the one officially settled by the *CNMC* in [23], as seen in *Table 7*. Compared to year 2016, this specific remuneration grew by 5,85%.

	Settlement re-assessment 2017		Accumulated settlement 2017		Balance (million €)
	Cumulative settlement (million €)	Liabilities to be paid by generators in L15/2017 (million €)	Cumulative settlement to be charged to GSB (million €)	Liabilities to be paid by generators in L15/2017 to GSB (million €)	
SOLAR PV	2440,46	1,72	57,99	0,03	2.496,70
SOLAR TE	1320,76	0,01	0,00	0,00	1.320,75
WIND	1470,46	0,04	2,66	0,04	1.473,05
HYDRAULIC	79,31	5,50	0,06	0,00	73,87
BIOMASS	309,26	0,38	0,48	0,00	309,36
TOTAL	5620,26	7,65	61,18	0,06	5.673,72

Table 7: Breakdown of renewable technologies specific retribution in fiscal year 2017. SOURCE: CNMC and own compilation.

Nevertheless, the author wishes to place on record that once this analysis was performed, in order to avoid rushing in the conclusions drawn process, *APPA* was contacted in several times and through different communication channels. In these contacts, the nature of the enquiry was deeply detailed but no further explanations were ever given. It must not be forgotten that *APPA* is an association of companies operating in the renewables sector which, among many other activities, yearly publishes the concerned report. This report is devoted to study the current status of renewable energies in Spain and the macroeconomic impact of their integration in the energy mix. A report which, in general terms, pays much attention to the social benefits associated to this integration and calls for an increment on public spending in the sector, under the pretext of fulfilling the objectives set out by current European directives.

It must be also noted that, during the simulation performed in this paperwork, resources were limited and no deep study of Complex Bidding conditions was carried out: these were just assumed to be as stated in 5.2. Still, since the beginning, the aim of this study has always been to provide the most actual, objective and realistic results of the effect renewable technologies integration has on electricity prices. Therefore, in order to fulfil its commitment, “complex” matched prices and energies arise as the final and most relevant output to be provided among all the results obtained from the simulation.

6.1. Sensitivity analysis

Thus, the effect of switching APPA’s simulation results (apparently reached under Simple Bidding conditions) to those that would have been reached under complex ones, on APPA’s macroeconomic analysis, is studied below. In order for this analysis to properly fit with the results published in the report, the used data samples under Simple Bidding conditions will be those of *Table 3* (the ones published by APPA). For the sample computed under Complex Bidding conditions, the results simulated in this paperwork (cases 2 and 4) will be used applying an increment of 3% to the underselling of *pool’s* prices (due to the 97% similarity between the results simulated in this project with simple bids and those published by APPA), so that results are coherent and comparable. Thus, the input data to be used in this analysis is detailed below in *Table 7* and *Table 8*.

<i>Magnitude</i>	<i>Units</i>	<i>Value</i>
<i>Underselling of Pool's price (Complex Bidding)</i>	€/MWh	7,18
<i>Total savings on Pool's price (Complex Bidding)</i>	million €	1.379

Table 8: Effect of renewables over electricity prices simulated under Complex Bidding conditions. SOURCE: Own compilation

<i>Magnitude</i>	<i>Units</i>	<i>Value</i>
<i>Underselling of Pool's price (Simple Bidding)</i>	€/MWh	10,23
<i>Total savings on Pool's price (Simple Bidding)</i>	million €	2.584

Table 9: Effect of renewables over electricity prices published by APPA. SOURCE: APPA and own compilation.

Under Complex Bidding conditions, the average hourly price matched at the Daily Market without renewable generation would have been of 59,42 €/MWh against the 62,47 €/MWh published in the APPA report, apparently under simple conditions. This is computed by means of using the settled the average *pool’s* price of 2017 at 52,24 €/MWh. Hence, *pool’s* price is incremented by 5,84% as a result of this switching, representing a difference of 1.205 million € on the savings generated by the renewable integration on the Daily Market operation.

Therefore, in order to compute the weight of *pool’s* price over final electricity prices for users, final hourly prices and energies negotiated in all *MIBEL* markets are accessed at *ESIOS* website (*Figure 31* and *Figure 32*). There is need to clarify that baseline scenario used to retrieve

the necessary input data to perform these calculations was the year 2017, so that the mean final electricity price for end users in 2017 was of 60,55€/MWh.

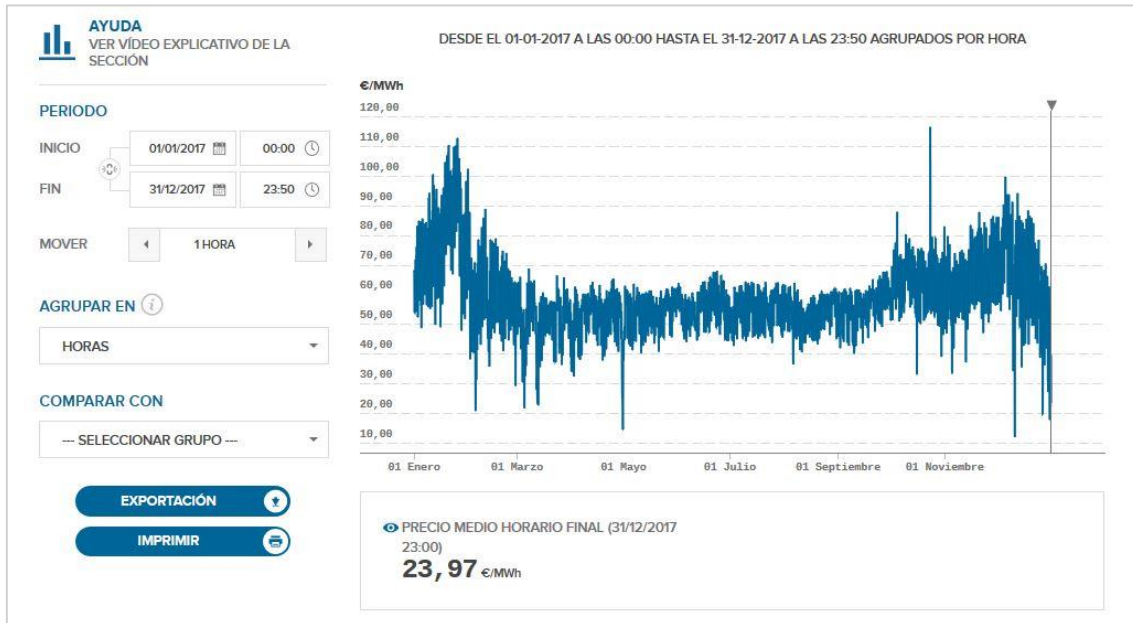


Figure 31: ESIOS's analysis tool for the end user hourly prices matched at all MIBEL markets. SOURCE: ESIOS.

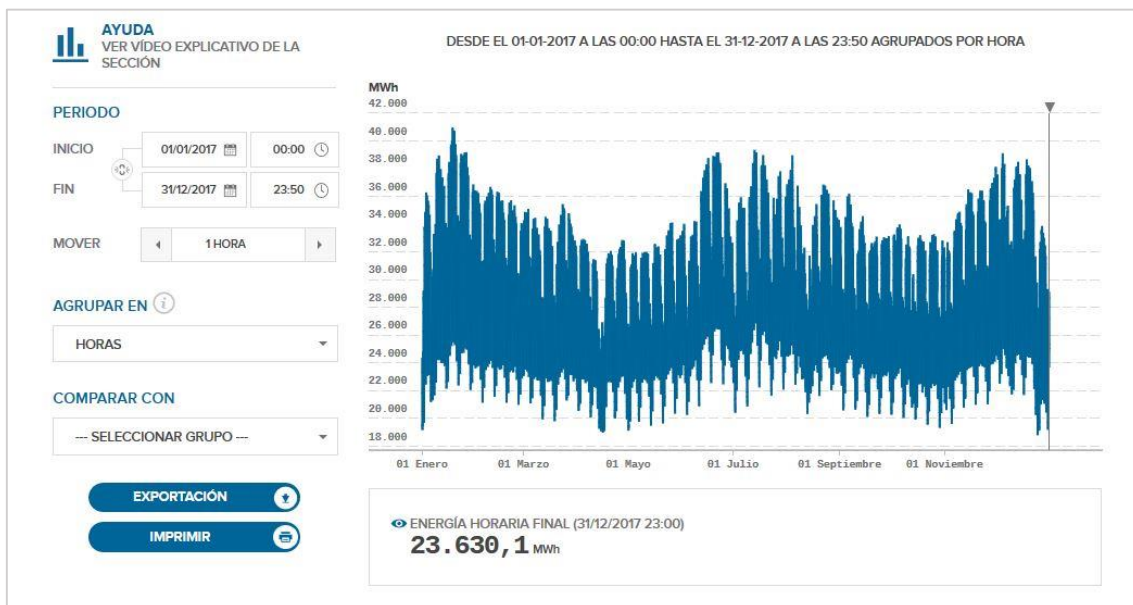


Figure 32: ESIOS's analysis tool for the end user hourly energies matched at all MIBEL markets. SOURCE: ESIOS.

Being the weighting of *pool*'s prices on final electricity prices calculated as follows:

$$Pool(\%) = \frac{p_{Pool} * e_{Pool}}{p_{Final} * e_{Final}} * 100$$

Therefore, it can be stated that the 68,43% of final electricity prices directly depends on *pool* prices. Hence, under Complex Bidding conditions, the increment on *pool*'s price resulting from the removal of the old *Special Regime* generation technologies from the energy mix, of 7,18 €/MWh magnitude, would have been translated into a final increment of 4,91 €/MWh, settling the final price of electricity for end users on 65,46 €/MWh. On the other hand, under Simple

Bidding conditions, the increment of 10,23€/MWh on *pool*'s price would have led to 7 €/MWh more expensive final prices, settling them at 67,55€/MWh.

Moreover, using the final energy negotiated in all *MIBEL* markets and considering the underselling of final prices, its savings can be computed: 1.203 million € under Complex Bidding conditions and 1.766 million € under Simple Bidding conditions.

Thus, the effect of this difference in prices over final savings can be calculated as the difference in prices times total energy negotiated in 2017 at all *MIBEL* markets. Then:

<i>Magnitude</i>	<i>Units</i>	<i>Value</i>
<i>Underselling of final price (Complex Bidding)</i>	<i>€/MWh</i>	4,91
<i>Total savings on final price (Complex Bidding)</i>	<i>million €</i>	1.203
<i>Underselling of final price (Simple Bidding)</i>	<i>€/MWh</i>	7,00
<i>Total savings on final price (Simple Bidding)</i>	<i>million €</i>	1.766

Table 10: Resume of type of bidding effect over final prices and savings for end users. SOURCE: Own compilation.

Hence, from the above, it can be concluded that not taking into account the Complex Bidding conditions in the simulation process leads to overestimate *pool*'s and final savings by 1.205 million € and 563 million €, respectively. Also, the final prices reduction resulting from renewables integration studied in APPA's report will have been sized 2,09 €/MWh bigger, while *pool*'s prices underselling would have been overestimated by 3,05 €/MWh.

7. CONCLUSIONS

To put it on a nutshell, the main implications of renewables on electricity prices will be outlined below, attending to the conclusions drawn from the analysis performed in this paperwork.

The main issue to take care of is renewable-generation technologies' sustainability from an economic point of view. As studied in this project, renewables do cheapen electricity prices: prices matched in the Day-ahead Market in 2017 were lowered approximately by 7,18 €/MWh (12,1% reduction), causing final electricity prices to also fall by 4,91 €/MWh (7,5 % reduction) due to the so called *merit-order effect*. Thus, the savings generated at the *pool* by this cheapening of prices was sized at 1.379 million € while end-users of electricity managed to save 1.203 million € in 2017.

Yet, it must ne also noted that the extrapolation of the results of the simulations performed in this paperwork to those that would have been obtained under Complex Bidding conditions relies on an initial assumption (that of 5.2). Therefore, it cannot be verified that the final results provided completely fit with the ones that would have been extracted by means of using complex bids. However, it is safe to say that these results are the ones that most closely approximate to reality, in contrast with those published in the *APPA* report: there are substantial grounds for believing that they were computed under the framework of Simple Bidding conditions. Thus, the savings and prices cheapening published in the report may be bigger than the actual ones.

However, in order to properly analyse renewables sustainability, these figures need to be put in contrast with the specific remuneration received by the renewable generation units in Spain. This is contributed by the purse of end-users of electricity, by means of paying the regulated term of their bills. During year 2017, which is the base line scenario for all the calculations and simulations performed in this project, this magnitude amounted to 5.674 million €. Nevertheless, must be noted that this amount had much to do with the several auctions held in 2017, which were executed with the aim of encouraging renewable generators to install new power capacity.

Thus, by means of comparing these figures with the savings generated by renewables integration to the end-users, a negative balance of 4.469 million € is noticed. Then, it can be assumed that production costs fell by 1.203 million € due to renewables integration while regulated costs grew up to 5.674 million €, as a result of the same fact. However, other savings must be also considered when studying the renewables paying-off. The costs avoided associated to the importation of fossil fuels and those related to the emissions allowances are key to understand renewables' economic sustainability. However, other not-so-measurable factors should be taken into account when contrasting these figures. From a strategic point of view, the integration of renewable technologies is a key movement to gradually reduce the dramatic degree of energy dependence of both the *EU* and especially Spain. By means of increasing the public spending in renewables, countries manage to cover bigger shares of their overall demand of electricity with renewables. This way, the security of supply is progressively shifted away from fossil fuel-based generation units, reducing the fuel imports and, consequently, making countries with high rates of renewables penetration into markets less vulnerable to the external policies of their hydrocarbon fuel exporters. Therefore, these incentives could be understood as a boost to update European energy mixes to the current technological and environmental requirements, settled by the *EU* for the future years.

Nevertheless, the scope of this project is limited to the analysis of the savings associated to the effect of renewables integration on electricity prices, as a result of its impact on the Day-ahead Market. In order to estimate a reliable and definitive conclusions regarding renewables financial self-sufficiency, the impact of the savings regarding fuel exports and CO₂ allowances into the purse of the end user should be properly computed. Still, *APPA*'s analysis can be used as an approximation to reach the first conclusions regarding this event. On its report, the effect of the above mentioned savings is considered, together with those generated in the 2017 Daily Market operation (apparently under Simple Bidding conditions). The balance between this savings and the specific remuneration received by renewable generation units is also negative, by 738 million € [1]. However, it must not be forgotten the exceptionality of year 2017 regarding renewable generation, due to climate issues. This fact has to be considered under the scope of the growing volatility of *pool*'s prices, especially noticeable in exceptional market situations, such as the concerned one.

Still, it can be said that the current overall remunerative regime devoted to incentive renewables generation and installation of power capacity is sustainable. Since 2013, no more premiums are provided to renewable generators. Instead, specific remunerations are paid on the basis of operational and investment parameters. Later modifications performed on the regulation have updated this remunerative regime. Currently, the amount to be perceived by generators for their operation term has been heavily constrained while the investment in renewable power capacity is now semi-financed through auction processes; which have turned to be a cost-effective mechanism. This way, since 2013, Spain has succeeded in eliminating the yearly generated tariff deficit in a considerable way. The revenue generated by the payment of access tolls has been big enough to face all regulated costs, achieving a yearly surplus trend that is expected to be held in the mid-term horizon. Moreover, the annuity payments associated the tariff deficit are expected to gradually decrease until the effective amortization of the accumulated debt of the Electric System occurs, expected to take place in 2030 [13].

Despite this, it is fair to say that the incentives devoted to renewable generation technologies are widely legitimated: they aim to absorb the positive externalities associated to their integration. Needless to mention all the benefits related to this integration in an almost infinite range of fields: climate change mitigation, job creation, tariff deficit reduction, industrialization of the rural world, increasing public awareness of climate issues, technological implications in different industries, reduction of the degree of external energy dependence, etc. Though, a net positive balance between the savings generated by them and public funds allocated to their integration would give even more consistency to any voices claiming for the support of renewables. However, the general thinking trend believes that this funding will probably not be held in the long run [21]: once renewables were able to satisfy most of the national electric demand and sufficient installed power came from renewable technologies, the public funds devoted to their integration could be suppressed. This way, renewable generation units would be able to operate in the electricity markets, auctioning energy at much lower opportunity costs than conventional generation units and enabling the overall reduction of market prices of electricity, as almost no fuels are involved in the overall renewable generation.

7.1. Future work lines

There are several improvements and extensions that could be implemented to the analysis performed in this thesis.

The most appealing future work line to follow could be the extrapolation of the performed simulation to the last ten years, especially when thinking of contrasting the results obtained with the figures published in past *APPA* yearly reports. This way, more relevant conclusions regarding the report solidness could be drawn, as years other than 2017 could be brought to analysis. It must not be forgotten that, even though reliable conclusions could be reached when studying this isolated year, it was an exceptional year from the scope of electricity generation. Bringing more years to the analysis will definitely add more consistency to the results reached. These could be weightily measured so that the overall uncertainty governing the analysis would considerably fall. However, and in order to do so, the data model should be upgraded in order to technically manage leap years.

As a complementary study, it would also be interesting to approximately estimate the implications of renewables integration on the operational, maintenance and ancillary services' costs of both the distribution and transport grids networking the national territory. The impact of these implications would be reflected in the regulated costs of the system, which would presumably rise as a result of the uncertainty regarding renewables generation predictions.

Moreover, and in a longer-term horizon, it would be interesting to estimate the implications renewables integration has on the strategies of conventional generators regarding their operation in energy markets. Some strategic behaviour could be developed towards their bid-auctioning tactics as a result of their damaged market revenue, for which renewables might be responsible.

8. REFERENCES

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9. ANNEXES

9.1. Script "rename_Files"

```

path='C:\Users\beare\Desktop\Dani\TFG\ficheros OMIE 2017 - copia';%path
to files
directory=dir(path);
for n=3:length(directory)%loop for each file representing a day from
year 2017

    directoryName=sprintf('%s\\%s',path,directory(n).name);
    newName=directoryName;
    newName(length(newName))='';%deletes "1" after "." standing for file
extension
    newName=sprintf('%sdat',newName);%adds "dat" to convert files to
.dat files

    movefile(directoryName,newName);%substitutes file names

end

```

9.2. Script "matching_Ren"

```

clearvars
close all
format compact
% matching process
path='C:\Users\beare\Desktop\Dani\TFG\ficheros OMIE 2017 - copia';%path
to PBF files
fileNames=dir(path);
filesNumber=length(fileNames)-2;
matchedPriceAcc=[];%preallocation of vector containing hourly matched
prices
matchedQuantityAcc=[];%preallocation of vector containing hourly matched
quantities

for iDay=1:filesNumber
    matchedPrice=[];%preallocates vector containing hourly matched prices
per day
    matchedQuantity=[];%preallocates vector containing hourly matched
quantities per day
    name=fileNames(iDay+2).name;
    pathFile=sprintf('%s\\%s',path,name);
    T=readtable(pathFile);
    T([1,end],:)=[];%deletes first and last rows
    T(:,9)=[];%deletes last column
    toDelete1 = strcmp(T.(8),'C');%deletes matched bids
    T(toDelete1,:)=[];
    toDelete2 = strcmp(T.(3),'PT');%deletes bids from Portugal in market-
splitting
    T(toDelete2,:)=[];
    S=table2array(T(:,[6 7]));%joins prices and quantities in a 2-column
matrix

    for N=1:length(S)
        S(N,:)=strrep(S(N,:),'.','');%erases "." standing for the thousands
        S(N,:)=strrep(S(N,:),',','');%replaces "," standing for the decimals
        by "."
    end
end

```

```

S(1,:)=[];%deletes first row containing headers (NaN)
quantities=str2double(S(:,1));%vector containing bid quantities
prices=str2double(S(:,2));%vector containing bid prices

hours=T(:,1);%vector containing hours (24 per file)
hours=table2array(hours);
hours(1,:)=[];%deletes first row containing titles (NaN)
hours=cellfun(@str2num, hours);

bidType=T(:,5);%vector containing bid types (selling/purchase)
bidType=table2array(bidType);
bidType(1,:)=[];%deletes first row containing headers (NaN)
bidType=cell2mat(bidType);

%sales=supply
sales=bidType=='V';%logical vector for selling bids
hoursSales=hours(sales);%vector containing selling bids per hour
quantitiesSales=quantities(sales);%vector containing quantities of
selling bids
pricesSales=prices(sales);%vector containing prices of selling bid

%purchases=demand
purchases=bidType=='C';%logical vector for purchasing bids
hoursPurchases=hours(purchases);%vector containing purchasing bids per
hour
quantitiesPurchases=quantities(purchases);%vector containing quantities
of purchasing bids
pricesPurchases=prices(purchases);%vector containing prices of
purchasing bids

if iDay==85%seeks day with time change
    for iHour=1:23
        %sales=supply
        hourlySales=hoursSales==iHour;%logical vector containing indexes
for selling bids at the given hour
        quantitiesSalesHourly=quantitiesSales(hourlySales);%indexed vector
containing quantities of the selling bids at the given hour
        pricesSalesHourly=pricesSales(hourlySales);%indexed vector
containing prices of the selling bids at the given hour
        %purchases=demand
        hourlyPurchases=hoursPurchases==iHour;%logical vector containing
indexes for purchasing bids at the given hour

        quantitiesPurchasesHourly=quantitiesPurchases(hourlyPurchases);%indexe
d vector containing quantities of the purchasing bids at the given hour
        pricesPurchasesHourly=pricesPurchases(hourlyPurchases);%indexed
vector containing prices for purchasing bids at the given hour
        %supply&demand matrices
        supply=[quantitiesSalesHourly';pricesSalesHourly'];
        demand=[quantitiesPurchasesHourly';pricesPurchasesHourly'];
        [xprice,xquantity]=Fmatching_Ren(supply,demand);%function calling
matchedPrice(iHour)=xprice;%saves function outputs
matchedQuantity(iHour)=xquantity;%saves function outputs
    end
elseif iDay==302%seeks day with time change
    for iHour=1:25
        %sales=supply
        hourlySales=hoursSales==iHour;%logical vector containing indexes
for selling bids at the given hour

```

```

    quantitiesSalesHourly=quantitiesSales(hourlySales);%indexed vector
    containing quantities of the selling bids at the given hour
    pricesSalesHourly=pricesSales(hourlySales);%indexed vector
    containing prices of the selling bids at the given hour
    %purchases=demand
    hourlyPurchases=hoursPurchases==iHour;%logical vector containing
    indexes for purchasing bids at the given hour

quantitiesPurchasesHourly=quantitiesPurchases(hourlyPurchases);%indexe
d vector containing quantities of the purchasing bids at the given hour
pricesPurchasesHourly=pricesPurchases(hourlyPurchases);%indexed
vector containing prices for purchasing bids at the given hour
%supply&demand matrices
supply=[quantitiesSalesHourly';pricesSalesHourly'];
demand=[quantitiesPurchasesHourly';pricesPurchasesHourly'];
[xprice,xquantity]=Fmatching_Ren(supply,demand);%function calling
matchedPrice(iHour)=xprice;%saves function outputs
matchedQuantity(iHour)=xquantity;%saves function outputs

end
else
    for iHour=1:24
        %sales=supply
        hourlySales=hoursSales==iHour;%logical vector containing indexes
        for selling bids at the given hour
        quantitiesSalesHourly=quantitiesSales(hourlySales);%indexed vector
        containing quantities of the selling bids at the given hour
        pricesSalesHourly=pricesSales(hourlySales);%indexed vector
        containing prices of the selling bids at the given hour
        %purchases=demand
        hourlyPurchases=hoursPurchases==iHour;%logical vector containing
        indexes for purchasing bids at the given hour

        quantitiesPurchasesHourly=quantitiesPurchases(hourlyPurchases);%indexe
        d vector containing quantities of the purchasing bids at the given hour
        pricesPurchasesHourly=pricesPurchases(hourlyPurchases);%indexed
        vector containing prices for purchasing bids at the given hour
        %supply&demand matrices
        supply=[quantitiesSalesHourly';pricesSalesHourly'];
        demand=[quantitiesPurchasesHourly';pricesPurchasesHourly'];
        [xprice,xquantity]=Fmatching_Ren(supply,demand);%function calling
        matchedPrice(iHour)=xprice;%saves function output
        matchedQuantity(iHour)=xquantity;%saves function output

    end
end

matchedPriceAcc=[matchedPriceAcc matchedPrice];%saves function output
in every loop
matchedQuantityAcc=[matchedQuantityAcc matchedQuantity];%saves function
output in every loop
end

```

9.3. Function "Fmatching_Ren"

%matching algorithm

```
function [xprice,xquantity]=Fmatching_Ren(supply,demand)
```

```

supply_ord=sortrows(supply',2);%matrix sorted by ascending prices
demand_ord=sortrows(demand',2,'descend');%matrix sorted by descending
prices

supply_ord_cum=[cumsum(supply_ord(:,1))';supply_ord(:,2)']';%accumulat
ed sum of supply quantities
demand_ord_cum=[cumsum(demand_ord(:,1))';demand_ord(:,2)']';%accumulat
ed sum of demand quantities

flag=0;
idem=0;
while flag==0
    idem=idem+1;
    quant_dem_acum=demand_ord_cum(idem,1);%selects current value from
the column vector for quantities
    price_dem=demand_ord_cum(idem,2);%selects current value from the
column vector for prices
    ioife=find(supply_ord_cum(:,1)>quant_dem_acum,1,'first');%finds
index for the first vector element with larger power than the curenent one
    quant_supply_acum=supply_ord_cum(ioife,1);%finds quantity for this
supply vector element
    price_supply=supply_ord_cum(ioife,2);%finds price for this supply
vector element
    if price_supply>price_dem %end loop when condition takes place
        flag=1;
    end
end

if quant_supply_acum>=quant_dem_acum
    xprice=supply_ord_cum(ioife,2);%sets supply price as matched
    xquantity=quant_dem_acum;%sets demand price as matched
else
    xprice=demand_ord_cum(idem,2);%sets supply price as matched
    xquantity=quant_supply_acum;%sets demand price as matched
end

end

```

9.4. Script "matching_NO_Ren"

```

clearvars
close all
format compact
% data retrieval from planned renewable-generation files
pathGenRen='C:\Users\beare\Desktop\Dani\TFG\Generación          EERR
programada\excel';%path to generation files
fileNamesGenRen=dir(pathGenRen);
filesNumberGenRen=length(fileNamesGenRen)-2;
quantityGenRenAcc=zeros(8760,1);%preallocates vector containing hourly
renewable generation

for iFile=1:filesNumberGenRen
    quantityGenRen=zeros(8760,1);%preallocates vector containing hourly
renewable generation per kind of energy
    name=fileNamesGenRen(iFile+2).name;
    pathFile=sprintf('%s\\%s',pathGenRen,name);
    T=readtable(pathFile);

```

```

if height(T)<8760 %seeks those files with null renewable generation at
determined hours of the year

    genRenHours=table2array(T(:,6));
    genRenHours=string(genRenHours);
    genRenHours =
datetime(genRenHours,'TimeZone','local','Format','yyyy-MM-
dd'T'HH:mm:ssz');
    t1=datetime(2017,1,1,0,0,0,'TimeZone','local','Format','yyyy-
MM-dd'T'HH:mm:ssz');
    allHours=[t1 t1+hours(1:8759)]';
    d=ismember(allHours,genRenHours);%logical vector showing at
which hours renewable energy was generated
    quantityGenRen(d)=T.(5);%generation vector containing 8760
elements (including those where generation is zero)
else
    quantityGenRen=T.(5);
end

quantityGenRenAcc=quantityGenRenAcc+quantityGenRen;%sum of all hourly
renewable generation of every kind
end

% matching process
path='C:\Users\beare\Desktop\Dani\TFG\ficheros OMIE 2017 - copia';%path
to PBF files
fileNames=dir(path);
filesNumber=length(fileNames)-2;
matchedPriceAcc=[];%preallocation of vector containing hourly matched
prices
matchedQuantityAcc=[];%preallocation of vector containing hourly matched
quantities

for iDay=1:filesNumber
    matchedPrice=[];%preallocates vector containing hourly matched prices
per day
    matchedQuantity=[];%preallocates vector containing hourly matched
quantities per day
    name=fileNames(iDay+2).name;
    pathFile=sprintf('%s\\%s',path,name);
    T=readtable(pathFile);
    T([1,end],:)=[];%deletes first and last rows
    T(:,9)=[];%deletes last column
    toDelete1 = strcmp(T.(8),'C');%deletes matched bids
    T(toDelete1,:)=[];
    toDelete2 = strcmp(T.(3),'PT');%deletes bids from Portugal in market-
splitting
    T(toDelete2,:)=[];
    S=table2array(T(:,[6 7]));%joins prices and quantities in a 2-column
matrix

    for N=1:length(S)
        S(N,:)=strrep(S(N,:),'.','');%erases "." standing for the thousands
        S(N,:)=strrep(S(N,:),',','.');%replaces "," standing for the
decimals by "."
    end

    S(1,:)=[];%deletes first row containing headers (NaN)

```

```

quantities=str2double(S(:,1));%vector containing bid quantities
prices=str2double(S(:,2));%vector containing bid prices

hours=T(:,1);%vector containing hours (24 per file)
hours=table2array(hours);
hours(1,:)=[];%deletes first row containing titles (NaN)
hours=cellfun(@str2num, hours);

bidType=T(:,5);%vector containing bid types (selling/purchase)
bidType=table2array(bidType);
bidType(1,:)=[];%deletes first row containing headers (NaN)
bidType=cell2mat(bidType);

%sales=supply
sales=bidType=='V';%logical vector for selling bids
hoursSales=hours(sales);%vector containing selling bids per hour
quantitiesSales=quantities(sales);%vector containing quantities of
selling bids
pricesSales=prices(sales);%vector containing prices of selling bids

%purchases=demand
purchases=bidType=='C';%logical vector for purchasing bids
hoursPurchases=hours(purchases);%vector containing purchasing bids
per hour
quantitiesPurchases=quantities(purchases);%vector containing
quantities of purchasing bids
pricesPurchases=prices(purchases);%vector containing prices of
purchasing bids

if iDay==85 %seeks day with time change
    for iHour=1:23
        %sales=supply
        hourlySales=hoursSales==iHour;%logical vector containing
indexes for selling bids at the given hour
        quantitiesSalesHourly=quantitiesSales(hourlySales);%indexed
vector containing quantities of the selling bids at the given hour
        pricesSalesHourly=pricesSales(hourlySales);%indexed vector
containing prices of the selling bids at the given hour
        %purchases=demand
        hourlyPurchases=hoursPurchases==iHour;%logical vector
containing indexes for purchasing bids at the given hour

        quantitiesPurchasesHourly=quantitiesPurchases(hourlyPurchases);%indexe
d vector containing quantities of the purchasing bids at the given hour

        pricesPurchasesHourly=pricesPurchases(hourlyPurchases);%indexed vector
containing prices for purchasing bids at the given hour
        %supply&demand matrices
        supply=[quantitiesSalesHourly';pricesSalesHourly'];
        demand=[quantitiesPurchasesHourly';pricesPurchasesHourly'];
        iHourYearly=iDay*24-(24-iHour);%counter standing for the number
of hour of the year
        quantGenRen_supply=quantityGenRenAcc(iHourYearly);%takes
renewable generation at the given hour

[xprice,xquantity]=Fmatching_NO_Ren(supply,demand,quantGenRen_supply);
%function calling
        matchedPrice(iHour)=xprice;%saves function outputs
        matchedQuantity(iHour)=xquantity;%saves function outputs
    end
end

```

```

elseif iDay==302 %seeks day with time change
    for iHour=1:25
        %sales=supply
        hourlySales=hoursSales==iHour; %logical vector containing
indexes for selling bids at the given hour
        quantitiesSalesHourly=quantitiesSales(hourlySales);%indexed
vector containing quantities of the selling bids at the given hour
        pricesSalesHourly=pricesSales(hourlySales);%indexed vector
containing prices of the selling bids at the given hour
        %purchases=demand
        hourlyPurchases=hoursPurchases==iHour;%logical vector
containing indexes for purchasing bids at the given hour

        quantitiesPurchasesHourly=quantitiesPurchases(hourlyPurchases);%indexe
d vector containing quantities of the purchasing bids at the given hour

        pricesPurchasesHourly=pricesPurchases(hourlyPurchases);%indexed vector
containing prices for purchasing bids at the given hour
        %supply&demand matrices
        supply=[quantitiesSalesHourly';pricesSalesHourly'];
        demand=[quantitiesPurchasesHourly';pricesPurchasesHourly'];
        iHourYearly=iDay*24-(24-iHour);%counter standing for the number
of hour of the year
        quantGenRen_supply=quantityGenRenAcc(iHourYearly);%takes
renewable generation at the given hour

        [xprice,xquantity]=Fmatching_NO_Ren(supply,demand,quantGenRen_supply);
%function calling
        matchedPrice(iHour)=xprice;%saves function outputs
        matchedQuantity(iHour)=xquantity;%saves function outputs
    end
else
    for iHour=1:24
        %sales=supply
        hourlySales=hoursSales==iHour; %logical vector containing
indexes for selling bids at the given hour
        quantitiesSalesHourly=quantitiesSales(hourlySales);%indexed
vector containing quantities of the selling bids at the given hour
        pricesSalesHourly=pricesSales(hourlySales);%indexed vector
containing prices of the selling bids at the given hour
        %purchases=demand
        hourlyPurchases=hoursPurchases==iHour;%logical vector
containing indexes for purchasing bids at the given hour

        quantitiesPurchasesHourly=quantitiesPurchases(hourlyPurchases);%indexe
d vector containing quantities of the purchasing bids at the given hour

        pricesPurchasesHourly=pricesPurchases(hourlyPurchases);%indexed vector
containing prices for purchasing bids at the given hour
        %supply&demand matrices
        supply=[quantitiesSalesHourly';pricesSalesHourly'];
        demand=[quantitiesPurchasesHourly';pricesPurchasesHourly'];
        iHourYearly=iDay*24-(24-iHour);%counter standing for the number
of hour of the year
        quantGenRen_supply=quantityGenRenAcc(iHourYearly);%takes
renewable generation at the given hour

        [xprice,xquantity]=Fmatching_NO_Ren(supply,demand,quantGenRen_supply);
%function calling
        matchedPrice(iHour)=xprice;%saves function output
    end
end

```



```

        matchedQuantity(iHour)=xquantity;%saves function output
    end
end

matchedPriceAcc=[matchedPriceAcc matchedPrice];%saves function output
in every loop
matchedQuantityAcc=[matchedQuantityAcc matchedQuantity];%saves function
output in every loop
end

```

9.5. Script "matching_NO_Ren_APPA"

```

clearvars
close all
format compact
% data retrieval from planned renewable-generation files
pathGenRen='C:\Users\beare\Desktop\Dani\TFG\Generación EERR programada
(APPA)';%path to generation files
fileNamesGenRen=dir(pathGenRen);
filesNumberGenRen=length(fileNamesGenRen)-2;
quantityGenRenAcc=zeros(8760,1);%preallocates vector containing hourly
renewable generation

for iFile=1:filesNumberGenRen
    quantityGenRen=zeros(8760,1);%preallocates vector containing hourly
    renewable generation per kind of energy
    name=fileNamesGenRen(iFile+2).name;
    pathFile=sprintf('%s\\%s',pathGenRen,name);
    T=readtable(pathFile);

    if height(T)<8760 %seeks those files with null renewable generation at
    determined hours of the year

        genRenHours=table2array(T(:,6));
        genRenHours=string(genRenHours);
        genRenHours =
datetime(genRenHours,'TimeZone','local','Format','yyyy-MM-
dd'T'HH:mm:ssz');
        t1=datetime(2017,1,1,0,0,0,'TimeZone','local','Format','yyyy-
MM-dd'T'HH:mm:ssz');
        allHours=[t1 t1+hours(1:8759)'];
        d=ismember(allHours,genRenHours);%logical vector showing at
        which hours renewable energy was generated
        quantityGenRen(d)=T.(5);%generation vector containing 8760
        elements (including those where generation is zero)
    else
        quantityGenRen=T.(5);
    end

    quantityGenRenAcc=quantityGenRenAcc+quantityGenRen;%sum of all hourly
    renewable generation of every kind
end

% matching process
path='C:\Users\beare\Desktop\Dani\TFG\ficheros OMIE 2017 - copia';%path
to PBF files
fileNames=dir(path);

```

```

filesNumber=length(fileNames)-2;
matchedPriceAcc=[];%preallocation of vector containing hourly matched
prices
matchedQuantityAcc=[];%preallocation of vector containing hourly matched
quantities

for iDay=1:filesNumber
    matchedPrice=[];%preallocates vector containing hourly matched prices
    per day
    matchedQuantity=[];%preallocates vector containing hourly matched
    quantities per day
    name=fileNames(iDay+2).name;
    pathFile=sprintf('%s\\%s',path,name);
    T=readtable(pathFile);
    T([1,end],:)=[];%deletes first and last rows
    T(:,9)=[];%deletes last column
    toDelete1 = strcmp(T.(8),'C');%deletes matched bids
    T(toDelete1,:)=[];
    toDelete2 = strcmp(T.(3),'PT');%deletes bids from Portugal in market-
    splitting
    T(toDelete2,:)=[];
    S=table2array(T(:,[6 7]));%joins prices and quantities in a 2-column
    matrix

    for N=1:length(S)
        S(N,:)=strrep(S(N,:),'.','');%erases "." standing for the thousands
        S(N,:)=strrep(S(N,:),',','.');%replaces "," standing for the
        decimals by "."
    end

    S(1,:)=[];%deletes first row containing headers (NaN)
    quantities=str2double(S(:,1));%vector containing bid quantities
    prices=str2double(S(:,2));%vector containing bid prices

    hours=T(:,1);%vector containing hours (24 per file)
    hours=table2array(hours);
    hours(1,:)=[];%deletes first row containing titles (NaN)
    hours=cellfun(@str2num,hours);

    bidType=T(:,5);%vector containing bid types (selling/purchase)
    bidType=table2array(bidType);
    bidType(1,:)=[];%deletes first row containing headers (NaN)
    bidType=cell2mat(bidType);

    %sales=supply
    sales=bidType=='V';%logical vector for selling bids
    hoursSales=hours(sales);%vector containing selling bids per hour
    quantitiesSales=quantities(sales);%vector containing quantities of
    selling bids
    pricesSales=prices(sales);%vector containing prices of selling bids

    %purchases=demand
    purchases=bidType=='C';%logical vector for purchasing bids
    hoursPurchases=hours(purchases);%vector containing purchasing bids
    per hour
    quantitiesPurchases=quantities(purchases);%vector containing
    quantities of purchasing bids
    pricesPurchases=prices(purchases);%vector containing prices of
    purchasing bids

```

```

if iDay==85 %seeks day with time change
    for iHour=1:23
        %sales=supply
        hourlySales=hoursSales==iHour; %logical vector containing
indexes for selling bids at the given hour
        quantitiesSalesHourly=quantitiesSales(hourlySales);%indexed
vector containing quantities of the selling bids at the given hour
        pricesSalesHourly=pricesSales(hourlySales);%indexed vector
containing prices of the selling bids at the given hour
        %purchases=demand
        hourlyPurchases=hoursPurchases==iHour;%logical vector
containing indexes for purchasing bids at the given hour

        quantitiesPurchasesHourly=quantitiesPurchases(hourlyPurchases);%indexe
d vector containing quantities of the purchasing bids at the given hour

        pricesPurchasesHourly=pricesPurchases(hourlyPurchases);%indexed vector
containing prices for purchasing bids at the given hour
        %supply&demand matrices
        supply=[quantitiesSalesHourly';pricesSalesHourly'];
        demand=[quantitiesPurchasesHourly';pricesPurchasesHourly'];
        iHourYearly=iDay*24-(24-iHour);%counter standing for the number
of hour of the year
        quantGenRen_supply=quantityGenRenAcc(iHourYearly);%takes
renewable generation at the given hour

        [xprice,xquantity]=Fmatching_NO_Ren(supply,demand,quantGenRen_supply);
%function calling
        matchedPrice(iHour)=xprice;%saves function outputs
        matchedQuantity(iHour)=xquantity;%saves function outputs
    end
elseif iDay==302 %seeks day with time change
    for iHour=1:25
        %sales=supply
        hourlySales=hoursSales==iHour; %logical vector containing
indexes for selling bids at the given hour
        quantitiesSalesHourly=quantitiesSales(hourlySales);%indexed
vector containing quantities of the selling bids at the given hour
        pricesSalesHourly=pricesSales(hourlySales);%indexed vector
containing prices of the selling bids at the given hour
        %purchases=demand
        hourlyPurchases=hoursPurchases==iHour;%logical vector
containing indexes for purchasing bids at the given hour

        quantitiesPurchasesHourly=quantitiesPurchases(hourlyPurchases);%indexe
d vector containing quantities of the purchasing bids at the given hour

        pricesPurchasesHourly=pricesPurchases(hourlyPurchases);%indexed vector
containing prices for purchasing bids at the given hour
        %supply&demand matrices
        supply=[quantitiesSalesHourly';pricesSalesHourly'];
        demand=[quantitiesPurchasesHourly';pricesPurchasesHourly'];
        iHourYearly=iDay*24-(24-iHour);%counter standing for the number
of hour of the year
        quantGenRen_supply=quantityGenRenAcc(iHourYearly);%takes
renewable generation at the given hour

        [xprice,xquantity]=Fmatching_NO_Ren(supply,demand,quantGenRen_supply);
%function calling
        matchedPrice(iHour)=xprice;%saves function outputs
    end
end

```

```

        matchedQuantity(iHour)=xquantity;%saves function outputs
    end
else
    for iHour=1:24
        %sales=supply
        hourlySales=hoursSales==iHour; %logical vector containing
        indexes for selling bids at the given hour
        quantitiesSalesHourly=quantitiesSales(hourlySales);%indexed
        vector containing quantities of the selling bids at the given hour
        pricesSalesHourly=pricesSales(hourlySales);%indexed vector
        containing prices of the selling bids at the given hour
        %purchases=demand
        hourlyPurchases=hoursPurchases==iHour;%logical vector
        containing indexes for purchasing bids at the given hour

        quantitiesPurchasesHourly=quantitiesPurchases(hourlyPurchases);%indexe
        d vector containing quantities of the purchasing bids at the given hour

        pricesPurchasesHourly=pricesPurchases(hourlyPurchases);%indexed vector
        containing prices for purchasing bids at the given hour
        %supply&demand matrices
        supply=[quantitiesSalesHourly';pricesSalesHourly'];
        demand=[quantitiesPurchasesHourly';pricesPurchasesHourly'];
        iHourYearly=iDay*24-(24-iHour);%counter standing for the number
        of hour of the year
        quantGenRen_supply=quantityGenRenAcc(iHourYearly);%takes
        renewable generation at the given hour

        [xprice,xquantity]=Fmatching_NO_Ren(supply,demand,quantGenRen_supply);
        %function calling
        matchedPrice(iHour)=xprice;%saves function output
        matchedQuantity(iHour)=xquantity;%saves function output
    end
end

matchedPriceAcc=[matchedPriceAcc matchedPrice];%saves function output
in every loop
matchedQuantityAcc=[matchedQuantityAcc matchedQuantity];%saves function
output in every loop
end

```

9.6. Function "Fmatching_NO_Ren"

```

%matching algorithm

function
[xprice,xquantity]=Fmatching_NO_Ren(supply,demand,quantGenRen_supply)

supply_ord=sortrows(supply',2);%matrix sorted by ascending prices
demand_ord=sortrows(demand',2,'descend');%matrix sorted by descending
prices

supply_ord_cum=[cumsum(supply_ord(:,1))';supply_ord(:,2)']';%accumulat
ed sum of supply quantities
demand_ord_cum=[cumsum(demand_ord(:,1))';demand_ord(:,2)']';%accumulat
ed sum of demand quantities

```

```

count=find(supply_ord_cum(:,1)>quantGenRen_supply,1,'first');%finds
index for matrix element with larger power than the renewable-generated
supply_ord_cum=supply_ord_cum(count:end,:);%deletes elements with
renewable generation
supply_ord_cum(:,1)=supply_ord_cum(:,1)-quantGenRen_supply;%subtracts
the renewable generation to the accumulated sum of quantities

flag=0;
idem=0;
while flag==0
    idem=idem+1;
    quant_dem_acum=demand_ord_cum(idem,1);%selects current value from
the column vector for quantities
    price_dem=demand_ord_cum(idem,2);%selects current value from the
column vector for prices
    ioife=find(supply_ord_cum(:,1)>quant_dem_acum,1,'first');%finds
index for the first vector element with larger power than the current one
    quant_supply_acum=supply_ord_cum(ioife,1);%finds quantity for this
supply vector element
    price_supply=supply_ord_cum(ioife,2);%finds price for this supply
vector element
    if price_supply>price_dem %end loop when condition takes place
        flag=1;
    end
end

if quant_supply_acum>=quant_dem_acum
    xprice=supply_ord_cum(ioife,2);%sets supply price as matched
    xquantity=quant_dem_acum;%sets demand price as matched
else
    xprice=demand_ord_cum(idem,2);%sets demand price as matched
    xquantity=quant_supply_acum;%sets supply price as matched
end

end

```

9.7. Script “load_OMIE_files”

```

% data retrieval from planned renewable-generation files
clearvars
close all
format compact

pathMatched='C:\Users\beare\Desktop\Dani\TFG\Precio&CantidadCasado';%p
ath to generation files
fileNamesMatched=dir(pathMatched);
filesNumberMatched=length(fileNamesMatched)-2;

%matched price
namePrice=fileNamesMatched(4).name;
pathFile_price=sprintf('%s\\%s',pathMatched,namePrice);
T=readtable(pathFile_price);

pool= strcmp(T.(2),'Precio medio horario componente mercado
diario');%only pool prices
hourlypriceComponents=table2array(T(:,5));
hourlypriceComponents=str2double(hourlypriceComponents);

```

```

matchedPrice=hourlypriceComponents(pool)';%indexing of pool prices

%matched quantity
nameQuantity=fileNameMatched(3).name;
pathFile_quantity=sprintf('%s\\%s',pathMatched,nameQuantity);
S=readtable(pathFile_quantity);

matchedQuantity=table2array(S(:,5))';

```

9.8. Script “compute_Savings”

```

clearvars
close all
format compact

load('matchedPrice&Quantity_OMIE.mat')
matchedPrice_Ren_CC=matchedPrice;
matchedQuantity_Ren_CC=matchedQuantity;
clear matchedPrice;
clear matchedQuantity;

load('matchedPrice&Quantity_NoRen.mat')
matchedPrice_NoRen_S=matchedPriceAcc;
matchedQuantity_NoRen_S=matchedQuantityAcc;
clear matchedPriceAcc;
clear matchedQuantityAcc;

load('matchedPrice&Quantity_Ren.mat')
matchedPrice_Ren_S=matchedPriceAcc;
matchedQuantity_Ren_S=matchedQuantityAcc;
clear matchedPriceAcc;
clear matchedQuantityAcc;

load('marketSplittingHours')
markSplit=logical(markSplit);

k=matchedPrice_Ren_CC-matchedPrice_Ren_S;
j=matchedQuantity_Ren_CC-matchedQuantity_Ren_S;

matchedPrice_NoRen_CC=matchedPrice_NoRen_S+k;

matchedQuantity_NoRen_CC=matchedQuantity_NoRen_S+j;

totalCost_NoRen_S=matchedPrice_NoRen_S.*matchedQuantity_NoRen_S;
totalCost_Ren_S=matchedPrice_Ren_S.*matchedQuantity_Ren_S;
totalCost_Ren_CC=matchedPrice_Ren_CC.*matchedQuantity_Ren_CC;
totalCost_NoRen_CC=matchedPrice_NoRen_CC.*matchedQuantity_NoRen_CC;

savings_Hourly_CC=totalCost_NoRen_CC-totalCost_Ren_CC;
savings_Yearly_CC=sum(savings_Hourly_CC);

savings_Hourly_S=totalCost_NoRen_S-totalCost_Ren_S;
savings_Yearly_S=sum(savings_Hourly_S);

p_low_S=savings_Yearly_S/sum(matchedQuantity_Ren_S);
p_low_CC=savings_Yearly_CC/sum(matchedQuantity_Ren_CC);

```

9.9. Script “compute_Savings_APPA”

```

clearvars
close all
format compact

load('matchedPrice&Quantity_OMIE.mat')
matchedPrice_Ren_CC=matchedPrice;
matchedQuantity_Ren_CC=matchedQuantity;
clear matchedPrice;
clear matchedQuantity;

load('matchedPrice&Quantity_NoRen_APPA.mat')
matchedPrice_NoRen_S=matchedPriceAcc;
matchedQuantity_NoRen_S=matchedQuantityAcc;
clear matchedPriceAcc;
clear matchedQuantityAcc;

load('matchedPrice&Quantity_Ren.mat')
matchedPrice_Ren_S=matchedPriceAcc;
matchedQuantity_Ren_S=matchedQuantityAcc;
clear matchedPriceAcc;
clear matchedQuantityAcc;

load('marketSplittingHours')
markSplit=logical(markSplit);

k=matchedPrice_Ren_CC-matchedPrice_Ren_S;
j=matchedQuantity_Ren_CC-matchedQuantity_Ren_S;

matchedPrice_NoRen_CC=matchedPrice_NoRen_S+k;

matchedQuantity_NoRen_CC=matchedQuantity_NoRen_S+j;

totalCost_NoRen_S=matchedPrice_NoRen_S.*matchedQuantity_NoRen_S;
totalCost_Ren_S=matchedPrice_Ren_S.*matchedQuantity_Ren_S;
totalCost_Ren_CC=matchedPrice_Ren_CC.*matchedQuantity_Ren_CC;
totalCost_NoRen_CC=matchedPrice_NoRen_CC.*matchedQuantity_NoRen_CC;

savings_Hourly_CC=totalCost_NoRen_CC-totalCost_Ren_CC;
savings_Yearly_CC=sum(savings_Hourly_CC);

savings_Hourly_S=totalCost_NoRen_S-totalCost_Ren_S;
savings_Yearly_S=sum(savings_Hourly_S);

p_low_S=savings_Yearly_S/sum(matchedQuantity_Ren_S);
p_low_CC=savings_Yearly_CC/sum(matchedQuantity_Ren_CC);

```

